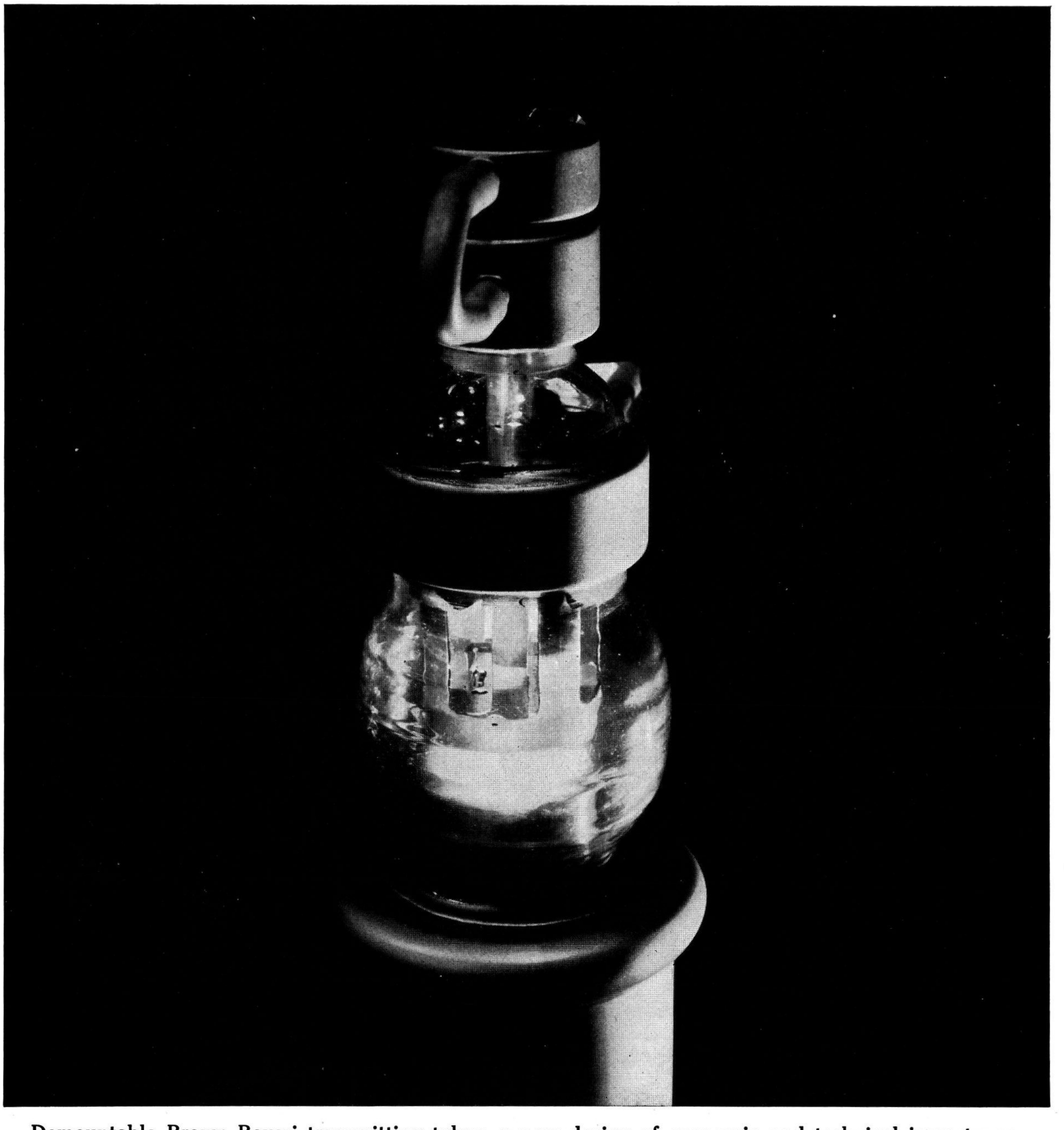
THE BROWN BOVERI REVIEW



Demountable Brown Boveri transmitting tubes, a new design of economic and technical importance.

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Special number: High frequency.

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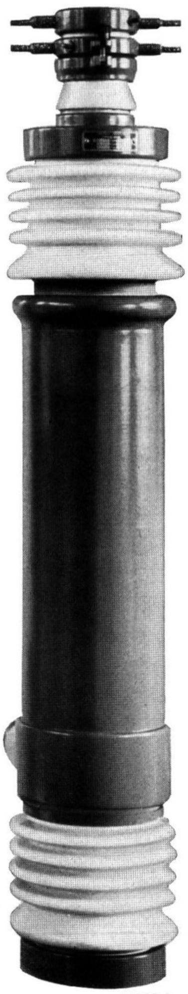
NEW DEVELOPMENTS
IN HIGH-FREQUENCY FIELDS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POWERFUL STATIONS FOR BROADCASTING AND FOR RADIO COMMUNICATION

equipped with Brown Boveri demountable transmitting tubes

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for low and for ultra-high frequencies

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for army, police and air protection

DIRECTIONAL TRANSMITTERS FOR AIRCRAFT AND SHIPPING

ground stations and board stations for aircraft and ships

REMOTE CONTROL, REMOTE MEASUREMENTS, REMOTE REGULATION

with directed or wireless carrier

MODERN BROWN BOVERI PRODUCTS

are the result of new investigations and established precision work

THE BROWN BOVERI REVIEW

THE HOUSE JOURNAL OF BROWN, BOVERI & COMPANY, LIMITED, BADEN (SWITZERLAND)

VOL. XXVIII DECEMBER, 1941 No. 12

CONTENTS:

INTRODUCTION.

HIGH-FREQUENCY engineering, based on the conceptions and works of Maxwell, Hertz and Marconi, has developed enormously in a comparatively short time. This was due to the vast field of application offered to it by the epoch-making events which marked the first World War and to the fact that de Forest and von Lieben's notable invention of the grid-controlled high-vacuum tube preceded the War. The end of the first World War saw technical science so far advanced that it was possible to turn the latest achievements to peaceful purposes. The expansion of commercial telephony and telegraphy through the aid of high frequency was, alone, sufficient to change considerably the face of things in the years following the War. This development, however, is relegated to the background when compared to the revolutionizing effect of wireless on the customs and general attitude of all classes of society. Especially at the present time, again unfortunately characterized by world-wide convulsions in military and political spheres, the fact that millions of people can listen in, practically without any time being lost in transmission, to reports on actual events going forward and are able to hear the voices of their leading statesmen adressing them directly, is of an importance which cannot be overestimated.

Switzerland did not participate to any marked degree in the developments just described, which, indeed, led into virgin ground from the technical point of view; she limited her activities in the high-frequency sphere to the manufacture of such products as found a ready market at home. To anyone who does not know the history of our country, this may seem natural and be put down to the smallness of Switzerland and to her very limited capacities as regards both size of population and available raw material. To do so would be to forget the remarkable pioneering work accomplished in Switzerland in the field of electrical power engineering. Such men as Bürgin, Thury and C. E. L. Brown, to mention only the most prominent, were not to be prevented by any such obstacles from pledging their good name, life-work and fortunes to the service of the, then, new field of power engineering. Not only did they harvest personal success thereby but they rendered invaluable services to our country. If we ask why, at a later date, in the high-frequency field, something similar did not occur again, we think the answer is that — apart from the fact that having no shipping deprived us of one incitement — high-frequency developments were very closely allied to the World War and the years just following it. We may also rightly assume that our industrial leaders were somewhat discouraged from seeking new outlets at that period by the economical difficulties with which the country was faced, so different from anything encountered before. But the mass of our people, as well, the source from which new creative forces must spring, was not in a favourable mood for such efforts in the after-war period. A general opinion that working conditions should be improved but that simultaneously the actual work produced by each individual should be reduced is not one conductive to success in any branch. We are convinced that this mental attitude, foreign to Swiss character, is a thing of the past and that it will so remain.

In deciding to make up for lost time in the high-frequency field, in so far as this was possible with our relatively modest resources, we were well aware that we could no longer embark on pioneering work such as the old masters already mentioned had accomplished. Technical science is already too far advanced for this. However, there can be no doubt that much remains to be done as, for example, in the field of the centimetre-length waves. As a matter of fact, there is hardly ever what could be termed a definite end to technical developments in any branch of engineering. Anyone, even when equipped with modest means only, who has enterprise and ordered knowledge of physics can attack the host of problems still unsolved in the high-frequency field. This number of our Review should give some information on the lines we have ourselves pursued and on those we intend to follow up.

As newcomers, we were faced with the necessity of following two different lines simultaneously. On the one hand, we had to see to getting a certain number of orders as early as possible, in order to get into touch with market requirements and to accustom our high-frequency personel, mostly made up of young men, to competitive market conditions. On the other hand, in pursuance of our traditions in other branches of engineering, we desired to contribute our part to new development by attacking problems yet unsolved. The practical accomplishment of this programme proved that the two lines could not be sharply divided, which is understandable. It will be comprehensible, however, that we will try to keep the two lines as distinct from one another as possible in the present number.

Transmitting plants offered a promising opening for our initial activities, because the manufacture of receiving sets had already been taken up by a number of Swiss firms. We would mention here the short-distance transmitting station at Kloten for directing aerial traffic which was put into service already in 1939. The military transmitting and receiving station combined which we built for the Swiss Army gave us an opportunity of introducing interesting improvements on existing apparatus especially as regards power per unit of weight. The building of the radio plant for the Zurich police gave us a still better opportunity of doing individual work. We would mention, here, our tests with medium and ultra-short wave lengths used simultaneously to allow flying squads to keep in touch with headquarters. The utilization of this two-wave system, found practicable, was then introduced, this by using frequency modulation a system which has hardly been used in Europe up till to-day. A great deal of work was necessary before the portable receiving sets were perfected; here the calling-up relay presented some special difficulties.

We developed a new line of demountable high-power transmitting tubes, in which the cathode can be replaced after it is burnt out, instead, of the whole tube having to be scrapped. This is going to mean considerable saving in big transmitting stations. These tubes offer interesting possibilities as regards subsequent adjustment of their characteristic to special operating conditions, which of course is out of the question with glass-sealed tubes. We have also turned our attention to tubes for producing decimetre and centimetre wave lengths. For this purpose it is impossible to use standard triodes even when special connections are resorted to. The difficulties which existed up till to-day in generating such short waves have prevented developments in this direction up till now. Nevertheless, these waves should render great services for general news propagation or for purposes of preserving secrecy. For these reasons we are studying the waves in question at the present time.

As to further work carried out in our development laboratories we would mention our coding and decoding devices for wireless telephony which, however, is only rather distantly connected with the science of high frequency. We think that there are further developments in store for wireless telephony and, under certain circumstances, telephony through wires, when it becomes possible to make the verbal message sent out unintelligible to anyone listening on an ordinary telephone receiver. Overseas telegraphy is already using apparatus of this kind, but they are very heavy and only provide limited secrecy. Our development work has already produced a portable equipment the degree of secrecy of which is already equal to that attained by coded telegrams. We were still not satisfied and have already fixed the basis for a new device from which we feel justified in expecting a great improvement, as regards secrecy, on anything produced so far. The great difficulty of mutual synchronization of transmitter and receiver had already been solved by us in the former apparatus; we, therefore, feel sure that there is now nothing to prevent our building a coding device to satisfy the requirements we consider essential.

Finally, we take great pleasure in expressing our sincerest thanks, here, to Professor Dr. P. Scherrer of the Swiss Federal Institute of Technology in Zurich for the valuable article he has been good enough to contribute to the present number. After we had built our short-wave transmitter for 40 kW at a wave length of 20 m which was the first work accomplished by our high-frequency department and which is used to supply the Cyclotron installed in the Physical Institute of the Swiss Federal Institute of Technology, we naturally desired to give our readers some information on the importance of the Cyclotron for the artificial transformation of atoms. Prof. Dr. Scherrer has not only fulfilled our hopes in this respect but his article carries us far into the fields of new physical and physiological investigations. We feel sure that our readers will join us in their appreciation of Prof. Dr. Scherrer's most interesting contribution.

(MS 811) *Th. Boveri. (Mo.)*

HIGH-POWER DEMOUNTABLE TRANSMITTING TUBES.

Decimal index 611.396.615.16

The most vital part of a transmitting station is the transmitting tube. We give a description here of newly-developed demountable tubes built up of metal and ceramic material, which are very rugged and have exceptionally advantageous economic, technical and physical qualities. They can be used for a great variety of outputs, voltages and frequencies. These are the first big transmitting tubes to be built in Switzerland.

I. INTRODUCTION.

DEVELOPMENT work in this new field was started at the beginning of the year 1937. At that time, we had as our aim to equip our transmitting stations with tubes of our own design. The first step was to decide on the most advantageous construction; here there was a choice between the ordinary glass-metal construction sealed by melting, without a pump, or the demountable, strong, ceramic-metallic design with high-vacuum pump constantly connected up. We decided in favour of the demountable tube, at first. It gave us the opportunity of making use of the wealth of experience gained in the mutator field, as far as the technic of vacua was concerned, and we were able to produce efficient transmitting tubes in a fairly short time, which was also due to existing manufacturing facilities. As a matter of fact, we succeeded, as early as the autumn of 1939, in carrying out tests on two tubes for 150 kW in the Beromünster transmitting station; these were very satisfactory. An official communication was broadcast by these tubes without any trouble. The successful carrying out of this task was rendered difficult by our having to adjust the characteristics of our tubes to those of the existing ones of melted-seal type in the plant.

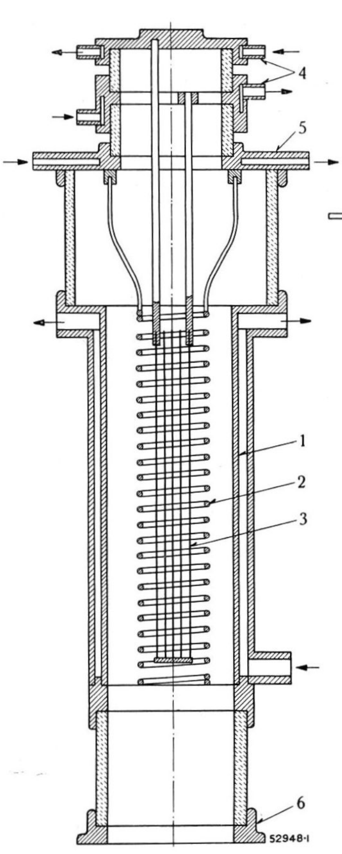
There were also economic reasons which influenced us to develop demountable tubes. The useful life of glass transmitting tubes is limited, as is well known, to some thousands of hours, because the hot cathode burns out after a time. The replacement of the tube is a costly business, especially for high-power units and must be periodically repeated; repairing does not pay. Our demountable design, on the contrary, allows of rapid and easy replacement of the cathode, this costs a few per cent of the price of the tube. In this way, the tube is endowed with an unlimited length of life.

Despite this, the tube without pump was studied further and to-day we are able to put forward a solution of our own, allowing of replacing defective cathodes without touching the melted seal between metal and insulation. This is a semi-demountable design of metal and ceramic material.

The demountable design is not new. As early as before 1920, attempts were made in England to increase to some kW the very modest power of the glass valve of about 100 W, by this method. However, this was not successful because the mercury-vapour pump used with its lowest operating pressure of 10^{-3} mm Hg, corresponding to the pressure of vaporization of the operating medium at room temperature, was quite unsuitable for the job. Known means to decrease the vapour pressure to admissible values are far too complicated, in practice. At the pressure in question, the control characteristic does not follow the space-charge law $Ia = KU^{\frac{3}{2}}$ but another one, on account of the ionization of the gas, this other law causes very marked irregularities in the characteristic thus making the tubes unfit for telephonic purposes especially. A transmitting tube begins to work faultlessly only from a pressure of 10^{-5} mm Hg and less. A few years later, the attempt was renewed in France, using a rotary molecular pump which, as is known, creates an absolute pressure of $< 10^{-5}$ mm Hg. The results produced transmitting tubes which could be used of up to about 10 kW anode loss. Development in this direction, however, remained stationary for years. In the meantime the art of making big melted-seal tubes had been mastered and, with these, anode losses of 300 kW were reached up to the year 1935. A few years earlier, the development of the demountable type of tube had also received a new impulse by the discovery of the oil-diffusion pump with the low operating pressure of only 10^{-5} mm Hg. Experimental transmitting tubes were built abroad up to 500 kW anode loss. To-day, we are able to manufacture demountable transmitting tubes for all loads, voltages and frequencies required by practical operating conditions.

II. DESIGN OF THE DEMOUNTABLE TRANSMITTING TUBES.

Figs. 1 a and 1 b show diagrammatically the difference between the demountable and the melted-seal type. This is the well known triode with cylindrical anode 1 of copper, a spiral control grid 2 of molybdenum or tungsten and a wire-cage cathode 3 made of tungsten. Here, the anodes are cooled by liquid while the grid and cathode radiate their heat to their surroundings. The cathode and the grid are connected to the artificially-cooled flanges 4 and 5 respectively. The glass-metal combinations of the 1 b design can support temperatures of over 100^0 C; as a rule, they do not require any artificial cooling. On the other hand, it is necessary to provide artificial cooling for all the flanges of design 1a in order to keep the sealing medium used between metal and ceramic material below the highest operating temperature admissible which is 50^0 C. The high-vacuum pump is connected below to the open transmitting tube 1 a at point 6.



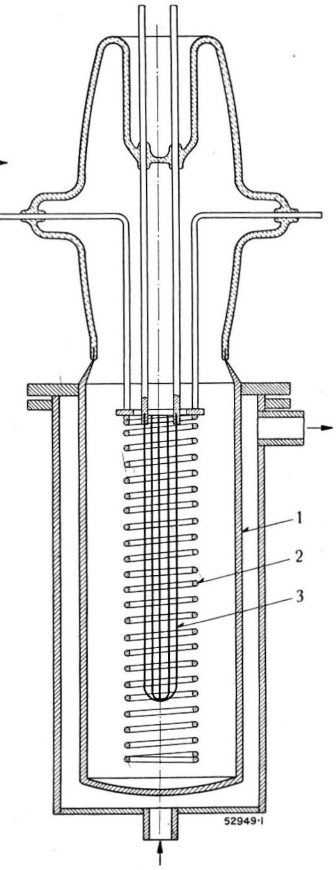


Fig. 1 a. — **Demountable transmitting tube.** **Fig. 1 b.** — **Melted-seal transmitting tube.**

This comparison shows the mechanical strength of the easily dismantled metal-ceramic design.

The weight of the tube alone is, despite this, hardly greater, because the anode which is its chief part can carry a specifically heavier load than in the case of the melted-seal design.

1. Anode. 2. Control grid. 3. Hot cathode. 4. Cathode flanges. 5. Grid flanges. 6. Pump flange.

—➤ Cooling water.

Transmitting tubes are apparatus which must satisfy a number of severe constructional requirements. They work at a very low pressure of less than 10^{-5} mm Hg. The operating frequency goes to some hundreds of M cycles. The ceramic parts, while being entirely gas-tight, must present very low dielectric losses and withstand temperatures up to some hundreds of degrees at the highest frequencies (molten quarz, for example, fulfils these conditions). The operating temperature of the hot cathode varies in the range of 2200 and 2300^0 C. The specific output W/cm^2 (output per unit of surface) on the anode is, for example, about five times higher than on the evaporator elements of a Velox boiler. The energy acting on the such as molybdenum, pure tungsten, molten quarz or special ceramic material. The assembly of different types of transmitting tubes with the high-vacuum pump is shown in Fig. 2. The pump also forms the base of the tubes. The demountable type allows of a practically unlimited increase in the output and voltage (see The Brown Boveri Review of 1941, No. 10). Fig. 3 shows an air-cooled type of low output and Fig. 4 a melted-seal design in ceramic and metal which can be partially demounted. It can be cooled either by air or by a fluid, according to the output and local conditions. The particular characteristic of this type is that a burnt out cathode or defective grid is easy

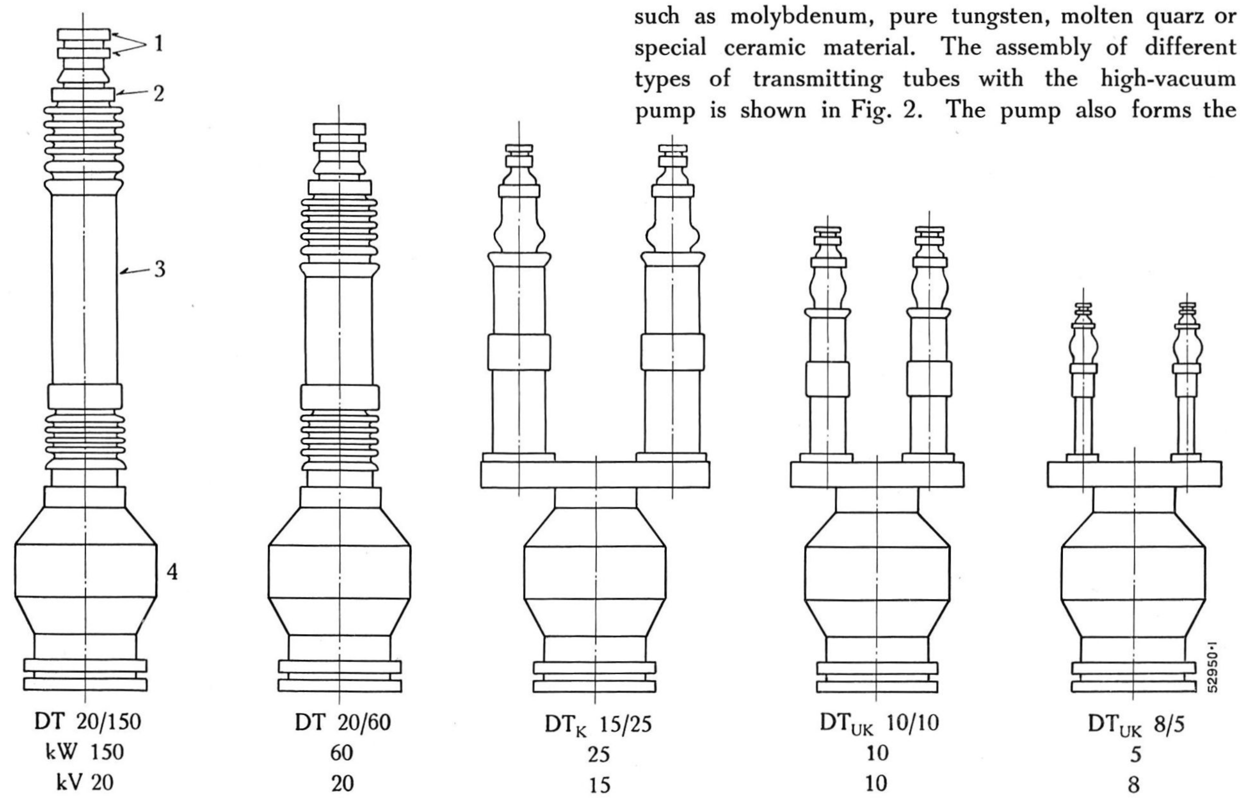


Fig. 2. — Demountable water-cooled transmitting tubes.

1. Connections for cathode. 2. Connections for grid. 3. Anode. 4. High-vacuum pump. kW. Anode losses. kV. Anode voltage.

The high-vacuum pumps also serve as supporting base for the transmitting tubes. According to output, these tubes can be mounted on the pump singly or in pairs.

anode is transformed into heat. The operating voltages can attain about 50 kV at high frequency and several hundred kV at industrial frequency.

The tube is built up of materials which are never, or very infrequently, used in big machines or apparatus

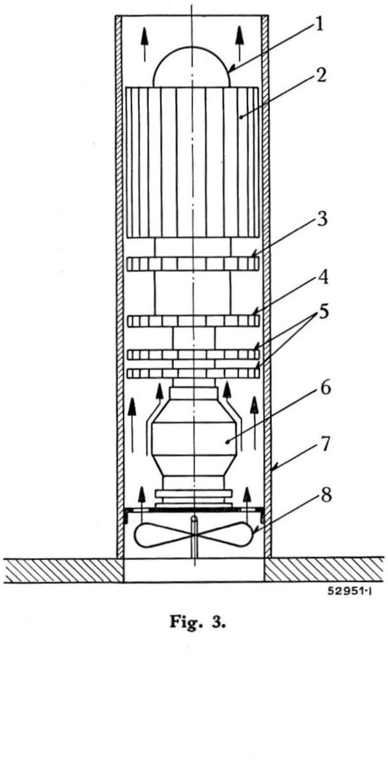


Fig. 3.

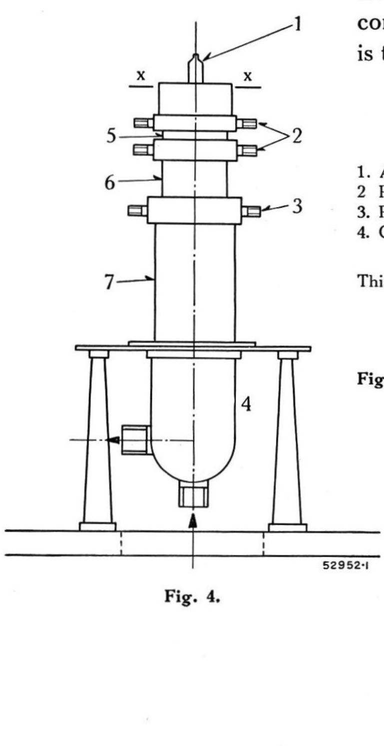


Fig. 4.

Fig. 3. — Demountable air-cooled transmitting tube.

1. Anode.
2 Radiator of the anode.
3. Radiator of anode flange.
4. Grid connection with radiator.
5. Cathode connections with radiators.
6. High-vacuum pump.
7. Air flow.
8. Fan.

This air-cooled type is specially suitable for low outputs and in plants where fluid cooling cannot be used.

Fig. 4. — Ceramic-metal melted-seal partially-demountable transmitting tube for fluid cooling.

1. Branch to be melted down to form seal.
2. Cathode connections.
3. Grid connection.
4. Anode.
5, 6, 7. Insulators.

A burnt-out cathode is also easily replaced with this kind of tube, after the tube has been cut open at x-x. After repairs, the tube opening must then be welded again, exhausted and definitely sealed by melting.

to replace in perfectly reliable manner, as is the case with demountable tubes. To this end, the tube is cut open at its metal top x—x, the cathode replaced the whole assembled again anew, exhausted and then welded gas tight again. It is not necessary to touch the metal ceramic melted seal. Of course, an operation of this kind must be carried out in the shop, but it can be repeated several times. Contrary to this, melted-seal tubes of the glass-metal type must be cut open on the glass side and sealed again by melting after the cathode has been exchanged. With small tubes this operation succeeds once or twice but big tubes must generally be replaced.

Fig. 5 shows a series of transmitter tubes for anode losses of 5 to 150 kW, voltages between 8 and 20 kV and a range of wave lengths of 1 to 100 m and over.

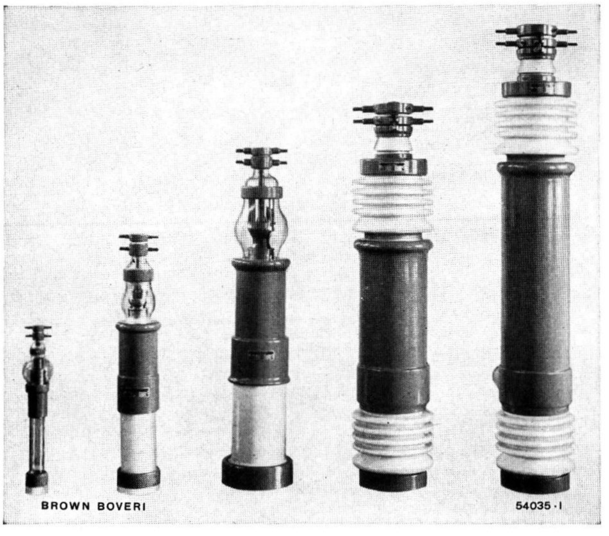


Fig. 5. — Demountable transmitting tubes already built
for 5 to 150 kW anode loss.
8 to 20 kV anode voltage.
10 to 500 kW max. effective output.
1 to 100 m wave length.
This constructively uniform series of tubes is ready for the market.

Fig. 6 shows a transmitting tube Type DT 20/150 with pump housing. A *Brown Boveri transmitter* for 100 to 200-kW effective output and two tubes of this type has been working successfully for several months in a broadcasting station. The type DT_k 15/25 is mounted in the Cyclotron plant of the Swiss Federal Institute of Technology in Zurich and work to great satisfaction. Two tubes in push-pull connection give an effective output of over 40 kW with a wave length of 18 m. In tests with Type DT_k 10/10 in push-pull connection and 5 m wave length, a usefull output of 10 to 15 kW was reached.

III. ADVANTAGES OF DEMOUNTABLE TUBES.

As compared to the standard melted-seal glass-metal design, the demountable design has a number of economic and technical advantages. Above all, there is the possibility already touched on of being able to replace burnt out or defective cathodes both quickly and easily. If proper preparations are made, not over 30 to 40 minutes are needed for a 150-kW tube. Before the tube can take over duty again, two to

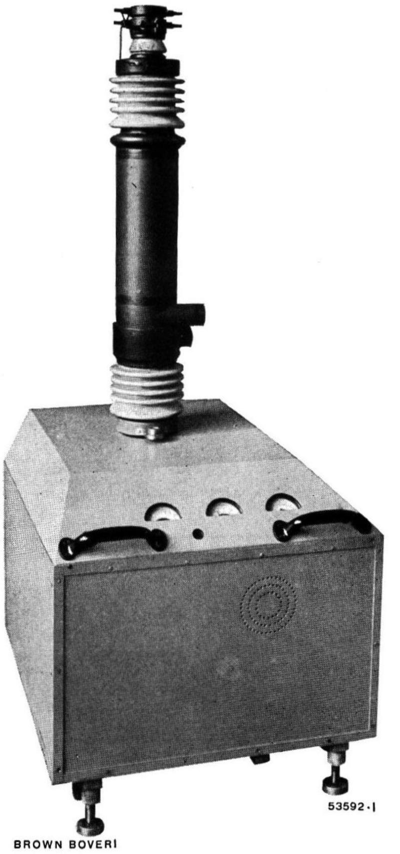


Fig. 6. — Demountable 150-kW tube.

The cathode can be replaced and the life of the tube is, therefore, unlimited. The high-vacuum pump and the first-stage pump with the automatic gear belonging thereto are lodged in the cubicle. The whole unit takes up little room and is mobile.

three hours must elapse, which are necessary to de-gass the new cathode. De-gassed spare cathodes kept under vacuum only require an additional 15 to 30 minutes. In practice, the cathode should never be allowed to burn out but should be replaced after some thousand hours, on the occasion of some longer pause in operation. Important plants should have complete spares ready for service. The possibility of replacing the cathode has a considerable economic advantage which is the greater the bigger the output of the transmitting tube.

The technical advantages are also considerable. Demountable transmission tubes can stand continuous overloading of about 50 % of the rated output which is an important quality when the output of the transmitter has to be increased, or when the apparatus is to be used to generate high-frequency power for industrial purposes. The mechanical strength of the design has also as result that the grid and incoming leads can withstand high-frequency currents which could not be allowed with melted seal tubes. At the beginning, it was the opinion that the demountable design could only be justified for outputs of over 50 kW anode losses. As developments went on, it was surprising to find that it was also of interest to build the small types down to 5 kW anode losses of the demountable type for ultra short wave lengths. We have developed designs having smaller inner capacities and inductivities and which thus allow of attaining relatively big useful outputs with short wave lengths.

Another outstanding property is the adjustability of the characteristic within determined limits, as for example during the tuning of a transmitter. Two tubes in push pull connection can be harmonized as regards the characteristics. Further, the grid characteristic can be chosen within a wide range, according to the use to which the transmitting tube is being put or the loading capacity of the first stage. The characteristic of the grid current in function of the grid voltage can be rising or falling and have positive or negative values here. This regulation is impossible in melted-seal rigid tube design. These tubes must be chosen in pairs to correspond with one another, because the method of manufacture always means deviations in the mutual position of the grid, cathode and anode and, therefore, differences in the characteristic.

Our layout with high-vacuum pump and first-stage pump may appear somewhat complicated and it takes up more room. The pump set with vacuum-measuring device and automaticity gear has, however, given exceptionally satisfactory results. Some of the molecular pumps have been running without a breakdown for over two years, the first-stage pump only runs intermittently.

Demountable transmitting tubes, water cooled and with high-vacuum pump in constant operation.

		Type of tube				
		DT_{UK} 8/5	DT_{UK} 10/10	DT_K 15/25	DT 20/60	DT 20/150
Admissible anode loss	kW	5	10	25	60	150
Anode voltage	kV	8	10	15	20	20
Attainable useful output[1]	kW	10	20	50	120	300
With a wave length of	m	6	8	12	50	70
Lowest wave length	m	0·9	2	3	4	6
Heating voltage	V	7	10	12	16	32
Heating current	A	75	145	145	430	430
Saturation current	A	4	8	10	50	100

[1] Per tube

To-day, we are in a position to deliver demountable transmitting tubes for a great variety of purposes, outputs, voltages and frequencies (see Table). Melted-seal types of lower output with air or fluid cooling are in course of preparation and will be put on the market shortly.

(MS 812) *A. Gaudenzi. (Mo.)*

GENERATORS FOR ULTRA-SHORT WAVES.

Decimal index 621.396.615.14
621.385.029.6

The way to generate ultra-short waves is to influence the velocity of the electron stream. Concentrations of electrons are created, by a sorting action, in an electron stream which was originally homogeneous; these concentrations deliver energy in a static-alternating field. The constructive realization of this principle leads, on the one hand, to the "transator", a kind of resonator which also provides the feed back and is traversed by a stream of electrons; on the other hand it leads to the "turbator" in which a circular flow of electrons is used to excite a cavity resonator.

I. INTRODUCTION.

THE enlargement of the wave band to include decimetre and centimetre waves means a considerable step forward in high-frequency science. The facility with which these waves can be formed into beams with the help of the simplest devices of the concave mirror type, permits of creating a science of directional rays for which there are a number of new technical applications. As the length of the wave is still relatively big as compared to molecules of air or tiny particles suspended in atmosphere, it is immune from the great disadvantage inherent to light-ray emissions, namely troublesome absorption and dispersion phenomena.

Contrary to short waves, the significance of which for radio work was only recognized when it was discovered what long distances they could travel, definite fields of application were at once apparent for the science of directional rays. What was wanting, above all, however, was a generator to produce such short waves. Two interesting examples can be mentioned among the many applications of these rays, namely:— the determination of distance and of direction and the application to wireless multi-channel transmission. The latter may have great possibilities of expansion in flat countries which are not yet equipped with a widespread telephone system. It is also quite possible that, in future, it may replace, to a great extent, our modern long-distance cable systems, on grounds of economy.

However, very great precision is required as regards the linearity of the modulation characteristic if the multi-channel system with one carrier wave is used, which, on account of its high frequency permits, at least theoretically, the superimposed modulation of several hundred channels of communication. To-day, it is still an open question how far it will be possible to reach practical results in this direction.

The science of valve design has reached an advanced degree of development, to-day, which meets all the requirements down to the metre-long waves for television. Valves for 1 m and less are characterized by small spacings and short electrode leads possessing small capacity. Wc would refer here to the acorn lamps which are tiny technical marvels. These known types of valve still work with, practically, instantaneous control of current by the grid voltage, that is to say the electron transit time in the valve is so short that it can be disregarded in comparison to the duration of an oscillation. If, however, this transit time becomes comparable to the duration of an oscillation, we get a phase displacement between grid voltage and controlled electron stream, which is translated into a flattening of the steepness of the characteristic. For a feed back connection, this means rendering the initiation of the oscillation more difficult and a big drop in the efficiency. This is the reason why the spacing of the electrodes is only a tenth of a millimetre and less in an acorn lamp for 60 cm wave length at about 200 V rated voltage.

II. PRINCIPLE OF THE ULTRA SHORT-WAVE GENERATORS.

If, now, we want to go over to still shorter waves (below 50 cm), an entirely new principle must be elaborated for the control of the electron flow. Instead of controlling directly by the grid voltage the strength of the electron stream, concentrations and rarefications in the flow of the electrons are caused in the originally homogeneous electron stream by sorting devices; these concentrations and rarefications are propagated with the velocity of the electrons themselves. The essential point is that these concentrations can be made to influence a current in a condenser with an oscillation circuit connected to it, in accordance with known laws; this current reacts so that it produces a retarding field for the electron groups. In this way, the d.-c. energy of the electron stream is converted into a.-c. energy by utilizing the electron transit time, because it is clear that the voltage on the condenser should not change in sign during the time the electrons are passing across it or only in such a way that the retarding action of the field is stronger than the accelerating action.

When not otherwise expressly stated, this is the general principle of generators based on transit time, although externally they may take a variety of forms. This principle has been the common property of high-frequency science for a long time now and the lively interest manifested by scientific and industrial laboratories in developing it has as object the creation of a constructively effective design, in other words towards producing stable and sufficiently powerful generators for decimetre and centimetre waves.

The above feature of transit time oscillations would, however, be incomplete without mentioning three other characteristics which are common and important:

1. The oscillation in generators of this kind must maintain itself and begin of itself. The basis thereof, as in standard valves, is the *feed back principle.* By means of the feed back an instability in the homogeneous stream of electrons is brought about, causing the oscillation to build up. However, this feed back is in most cases so closely connected to the process of electronic movement that it is not visible externally, at all.
2. The smallness of the oscillation circuit necessary for such short waves means *perfect constructive combination* of the said circuit with the above-mentioned coupling element which provides for the transmission of energy from the electron current to the circuit. All these parts are, usually, lodged in the valve itself.
3. Recently, these oscillating circuits have been designed as *cavity resonators.* These are metallic hollow bodies which prevent radiation and are characterized by an especially high quality factor (up to 10^5 as compared to 10^2 in standard oscillation circuits). This property is of great importance in generators in which the electrons should be retarded after a single passage, because a high a.-c. voltage is required for this. The cavity resonators have also the technical advantage of allowing the whole apparatus to be made of metal, the metallic body of the resonator also forming the vacuum chamber for the electronic discharge.

An idea can be formed of the demands made on the sorting device as regards precision when the cycle, which is the decisive factor in the transit time and not the length of wave, is considered. In the case of a 3 cm wave length corresponding to a frequency of 10^{10} cycles, the film strip would be 10,000 km long if recorded on an oscillograph during one second, assuming a scale of 1 mm per cycle.

In the following paragraphs, a few of the many designs are touched on which have been developed along lines which seem promising to us and appear to be distinguished from other known generators by certain advantageous properties.

III. DESIGNS AND PROPERTIES.

1. *The "Transator".*

Fig. 1 shows a generator for 25 cm wave length and $1 \cdot 2$ watt high-frequency output. Here, the manner in which the oscillations are produced is particularly easy to follow and we give some closer details on the subject, with the help of the example in question. A ray of electrons streams up axially from the cathode lodged in the lower part of the valve, passing through an electronic lens system which also makes the modulation possible. The oscillation circuit is composed, according to Fig. 2, of a Lecher system, the lower side of which is short-circuited, and the two double grids. Calculation shows that it is possible to generate stationary oscillations by means of coupling with the electron ray [1].

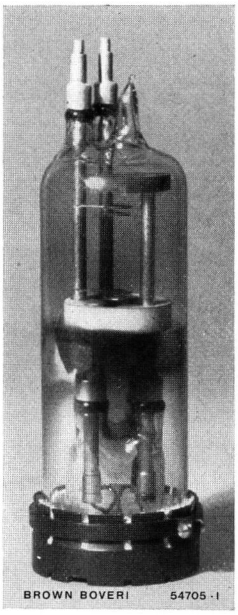


Fig. 1. — Transator for decimetre wave lengths.

The cathode is embedded in a new kind of ceramic holder. The holes through the accelerating electrode and through the four grids are for attaining effective concentration of the electron ray.

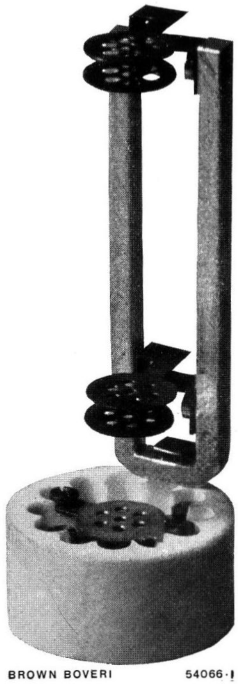


Fig. 2. — Oscillation system of the transator shown in Fig. 1.

It is designed as a Lecher system of quarter-wave length. The simple and strong construction also permits of keeping the losses low.

The high-frequency voltage generates on the lower double grid a velocity control of the electrons, but does not control the current, however. In the space up to the next double grid, the electrons travel at different speeds, slow and fast electrons following one another, faster and slower electrons combine in the space between the two pairs of grids and in the space between the two upper grids we get the desired conglomerations of electrons. This acts, as has been already mentioned, as conduction capacity for the resonance circuit. A part of the voltage induced on the capacity is tapped by the lower control electrode, which causes the oscillations to be started and maintained.

The feed back is very visible here. The high-frequency energy is led out through the agency of a Lecher system by direct coupling to the resonance circuit. The anode in the upper part of the tube serves to absorb the electrons. The combination of these elements into an organic whole has the advantage of very great simplicity when compared to one formed of two separate resonance circuits tuned to one another.

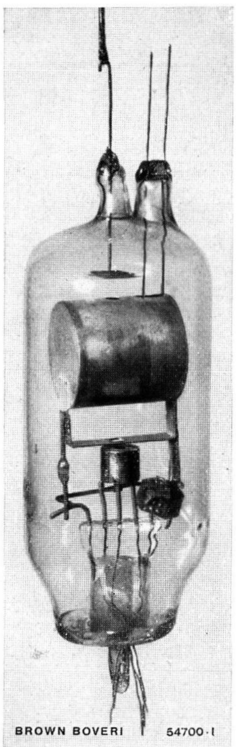


Fig. 3. — Transator with cylindrical resonator.

The resonator, designed as concentric Lecher system, is 3 cm long corresponding to a wave length of 6 cm.

Fig. 3 shows a generator built to this principle. Here the resonance circuit is represented by a concentric Lecher system closed on both sides and through which the flux of electrons streams transversally. It is a special type of cavity resonator, the inherent wave of which is equal to the double length of the cylinder. The control electrode is formed by the double wall of the lower electron penetration space, the conduction electrode by the double wall of the upper electron penetration space. The length of the transit space is determined by the diameter of the interior tube. The energy led out is taken by direct coupling to the resonance circuit. The combination: — control electrode, transit space, conduction electrode and feed back form along with the resonance circuit a very simple system from the constructive point of view. Further, on account of its geometrical simplicity and also because there are no losses by radiation, it is possible to calculate it quantitatively completely.[2] Determined dimensions are given for the radii of the two concentrical tubes for a given voltage of acceleration and a given length of wave. From this, the loss resistance of the system can be calculated. For a 6 cm wave it attains $6 \cdot 10^4$ ohms. This leads to

[1] F. Lüdi, Helv. Phys. Acta Vol. XIII, Fascic. Sec. (1940) page 122. — F. Lüdi, Helv. Phys. Acta Vol. XIII, Fascic. Sext. (1940) page 498.

[2] F. Lüdi: — will be published shortly in the Helv. Phys. Acta.

an electron current of 14 mA for initiating the oscillation, this with a coupling of the load circuit which is practically zero. The frequency stability is determined, for this example, for one per cent velocity change of the electrons (corresponding to two per cent voltage change), at $0 \cdot 1$ per thousand. With a wave length of 6 cm, this corresponds to a change in frequency of $5 \cdot 10^5$ cycles. A relatively big change like this is, in principle, a feature of all self-excited transit time generators. It is due to the variation in in the transit time of the groups of electrons which always corresponds to a change in the feed back phase.

The characteristic of both the generators described is the translation movement of the electrons passing through an oscillating system composed of one single resonator. This design is, therefore, known under the name of *"Transator"*.

2. *The "Turbator".*

The resonator shown in Fig. 4 [1] belongs to a generator designed according to another constructive principle. The emission of electrons takes place in the axis of the system. Through the action of a constant radial electric field and of an axial magnet field a circular electron stream is produced. The segments S are so arranged alternatively on the sides of the cylindrical cavity resonator that an a.-c. voltage is produced between neighbouring segments. The action on the electrons is more complicated than in the former examples; it can also be explained theoretically.[2] The result is somewhat as follows:— The alternating field in the slits along with the constant magnet field produces an acceleration or retardation of the electrons in tangential direction, according to the initial phase, and a sorting effect is produced by this. We get concentrations and rarifications in the circular electron stream which was, originally, homogeneous. Contrary to the two first generators described, these aglomorations of electrons then deliver up successively their energy, originating from the electric constant field, to the alternating field of the cavity resonator. The feed back, although not visible, exists all the same. One and the same segment forms the control electrode and the conduction electrode. The appearance of this generator is somewhat like that of an a.-c. machine. The cavity resonator determining the frequency along with the segments resembles a stator while the rotation of the electron agglomerations corresponds to the movement of the rotor, thus the name of *"Turbator"* seems appropriate for this type of generator.

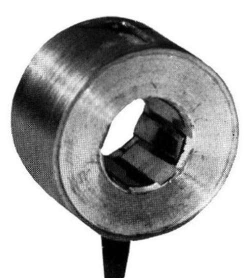


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Fig. 4. — Oscillation system of a turbator.

The resonator is built of very heat resistant and well degassed metal.

This extremely simple design has the following advantages:— the circular stream of electrons make an electronic lens system, such as the transator needs, superfluous.

The wave length is determined sharply by the cavity resonator, that is by its diameter and the capacity between the segments. As is known, a number of neighbouring waves appeared simultaneously in the older magnetrons, which is undesirable for transmission purposes. The combination into a whole of the segments and the cavity resonator is a very good solution both as regards the load of the anode and the possibilities for influencing the emission of electrons. Further, the result is a stout all-metal piece of apparatus.

A first generator of this type built, Fig. 4, has a high-frequency output of about 1 watt, at a wave length of $10 \cdot 2$ cm, measured by means of an adjustable cavity resonator, with an absolute precision of less than $0 \cdot 1$ mm. The tube oscillates stably without it being necessary to put stabilizing devices on the network connection; it reveals no back-heating effect. With a suitable control electrode, we get nearly a hundred per cent modulation control of the tube without any marked change in frequency. Here the magnet field is only 400—500 Gauss.

This weak field allows of using light permanent magnets, a factor of importance for the apparatus.

The generators which have been known for a long time under the names of *retarding-field tube* and *magnetron*, make use of another sorting mechanism for producing groups of electrons. Here, the so-termed false phase electrons are eliminated from the electron stream by means of a special electrode. This process is only partly successful. For this reason, only low outputs at poor efficiencies are attained.

Even here, however, it has been found possible to attain the advantageous relationship of the phase-focussed electrons and the utilization of cavity resonators. Only by means of the most careful investigations, of all the elements which produce the oscillation, is it possible to reach this stage of progress as well as the other improvements described previously.

(MS 813) *Dr. F. Lüdi. (Mo.)*

[1] F. Lüdi, Tagesbericht der schweiz. phys. Gesellschaft of 7th and 8th Sept. 1941.

[2] F. Lüdi, Helv. Phys. Acta, Vol. XIII Fasc. Sext. (1940) page 77.

METHODS FOR THE AUTOMATIC SCRAMBLING OF SPEECH.

Decimal index 621.396.47

The guarding of the secrecy of a conversation is of great importance, not only for military but also for commercial communication. This is specially true for multiple-channel wireless transmission which holds many possibilities of expansion.

We have been studying for a considerable time now the problems relative to the scrambling of speech and the improvement of automatic coding devices for telephonic or telegraphic transmission.

The fundamental scrambling methods, as well as the processes we have developed, ourselves, to ensure a better transmission secrecy, are described and compared in this article.

I. INTRODUCTION.

Wireless transmissions can, as is known, be picked up in many cases by unauthorized listeners. Even in cable or line transmission, there are ways of listening in. For these reasons, telegrams are often sent coded. But devices for coding speech transmission exist as well. From the coded signal transmitted, the receiver making use of a decoding device, adjusted to the coding programme being used, reproduces the original message in clear form.

A known method to complicate undesired listening in on wireless messages, is to change the carrier wave continually or suddenly at intervals according to a programme agreed on in advance. It is however possible for a listener in having at his disposal a wide-band amplifier or an automatic quick-tuning equipment to receive and understand such messages without knowing in advance the tuning programme being used. Further, systems of this kind are undesirable on account of the large frequency band width required. Other suggestion to increase the secrecy by high-frequency carrier modulation are not suitable for multiple use, because scrambled messages are often transmitted by ordinary telephone lines which have limited frequency band possibilities. In many cases, for example the installation of coding devices in telephone central stations or even at the private adress of telephone subscribers is desirable quite independently of whether the message is wireless-transmitted on part of the distance or not. This means that low-frequency scrambling is necessary without widening the frequency band.

In known telegram codifying methods the ordinary sequence of the signs or series of signs are replaced by other signs or series of signs in an order which can be altered in accordance with a programme settled on in advance (substitution process). Often, the order in which the signs are given out is, itself, periodically changed (transposition process). Both transmission processes can be utilized automatically with the help of suitable apparatus.

It is more difficult to scramble spoken messages and then to reproduce the original words, as words and sentences spoken are not composed of simple and separate signs which, like letters and numbers, are easy to codify. Speech vibration is a continuous phenomen on comprising many wave shapes of different amplitudes, frequencies and duration, corresponding to its various tones and possibilities of expression.

II. THE COMPOSITION OF SPEECH AND SCRAMBLING POSSIBILITIES.

Vowels and consonants have very different characters due to the different ways of pronouncing them. The vowels "v" are composed of a fundamental wave and many harmonics. They are distinguished one from another by their fundamental frequency $f_o = \frac{\omega_o}{2\pi}$ and the amplitudes "a" of their components.

$$v = V(t) \sum_{k=1}^{n} a_k(t) \cdot \cos\left[k \int \omega_o(t)\ dt + \varphi_k\right]$$

The function V (t) expresses the interruptions due to speech pauses and consonants. The vowels occurring in speech are, thus, represented by a blend of oscillations, modulated in frequency and amplitude occurring intermittently and having a tone.

On the other hand, the consonants "w" have a continuous amplitude spectrum, without marked fundamental oscillations, that is to say they have a noise character.

$$w = W(t) \int_{o}^{\omega_m} \left\{ b(\omega) \cdot \cos(\omega t) + c(\omega) \cdot \sin(\omega t) \right\} d\omega$$

In automatic coding of speech, these complex oscillations are modified according to a system agreed upon. It is, however, to be kept in mind that the slightest language particularities are heard by a trained ear. They may suffice to make certain words comprehensible or to allow a guess at them. A listener in for whom the message is not intended can also try to find out all or part of the coding process by systematically changing the coded signals. After deciphering a part of the text the remainder is easier to analyse as, little by little, new suppositions on the remaining contents are possible. If the key remains the same, that is, if the relation between the uncoded speech and the coded speech is always the same, it would be easy to discover the key after having deciphered part of the message. For this reason it is necessary to change the scrambling constantly in accordance with a programme. Finally, the requirement remains that the decoded message, received by the rightful receiver, should be sufficiently clear.

Considering all these difficulties and requirements, it is easy to conceive that most of the suggested automatic speech-coding systems are either a technical impossibility or do not offer sufficient guarantee as to secrecy.

III. SUBSTITUTION METHOD.

A well known scrambling process consists in giving a definite frequency shift, agreed on, to the initial clear-speech frequency. This frequency substitution is obtained by modulating the original frequency with constant or changing auxiliary frequencies which, in general, are selected outside the voice range frequency-band.

A simple modulation of the voice vibrations x by means of an auxiliary frequency g_1 gives two mixed resultant frequencies at the output of the modulator M, one being the sum of the voice frequencies and auxiliary frequency, the other their difference. In Fig. 2 the "sum" frequencies are eliminated by a low-pass filter TP, so that only the "difference" frequency z_a is passed. Its composing frequencies fall in the original voice frequency range if the auxiliary frequency corresponds to the maximum voice frequency. On the receiver side, with a similar device, a modulation-product is obtained from the oscillations transmitted and an auxiliary frequency "g_1" from which the clear language is reconstructed. This frequency inversion often used is not sufficient to meet practical exigencies because the auxiliary frequency necessary to decipher the message can be easily determined by trying.

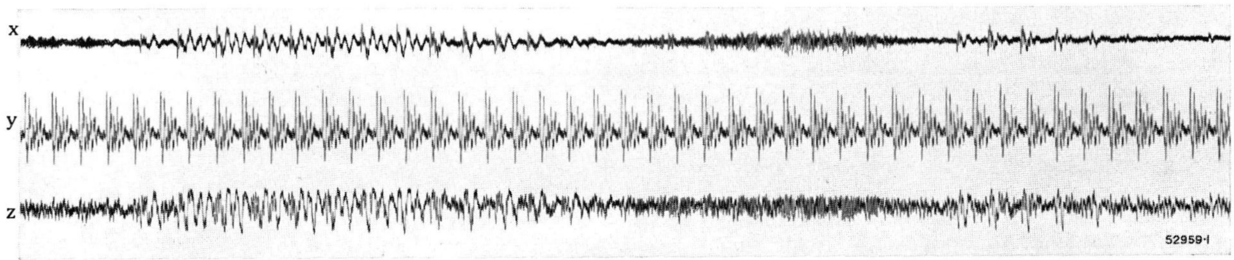

Fig. 1. — Noise-tone method.

The coded signal z results from the combination of the clear signal x and the noise-tone y. This coding is insufficient, as many particularities of x can still be found in z.

The "addition" process, in which an interfering frequency is superimposed on the signal frequency, is quite insufficient. In Fig. 1 we give under "x" as speech wave a length cut out of the oscillogram of the word "Gesellschaft" and under "y" the interfering wave, in this case the vowel "a". In the resultant signal oscillogram "z" we find again many particularities of "x". For an exercised ear, a distinguishing of the original signal is still easier. Even if the interference amplitude is a multiple of the voice amplitude, certain words can, nevertheless, be heard. The inevitable phase and amplitude distorsion produced by the transmission so modifies the interfering signal wave y superimposed that correct reconstruction of the speech x at the reception end with the help of an opposed interference signal wave is impossible.

Processes in which the message is transmitted by a device with non-linear characteristic, in order to make it unintelligible are also insufficient. The original message is reconstructed at reception by using a non-linear characteristic device on the receiver side, as well. With this system, too, the keyed message is never completely incomprehensible and a satisfactory reconstitution at reception is impossible because of the inevitable phase and amplitude distorsion due to the transmission. The same objections apply to many processes maintaining message secrecy by phase or amplitude distorsion, by interruption or mixing with other oscillations.

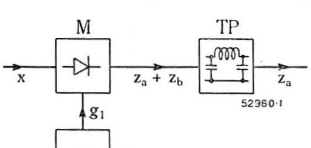

Fig. 2. — Inversion method.

By modulation of the clear signal x with an auxiliary frequency g_1, we get the inverted signal z_a. This coding is insufficient as the auxiliary frequency g_1 made use of, can easily be determined by tests.

The voice frequencies, shifted by a first modulation, are, often, modulated a second time by a frequency "g_2". In the arrangement shown in Fig. 3, the "difference" frequencies of the first modulation are suppressed by a high pass filter HP, and the "sum" frequencies of the second modulation, by a low pass filter TP, so that a signal z_c results, the components of which are those of the message transmitted shifted

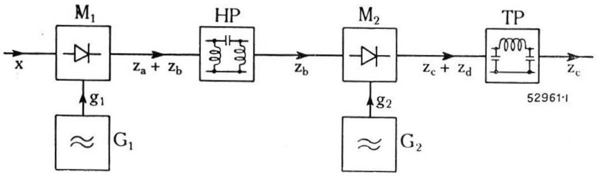

Fig. 3. — Frequency-shifting method.

By double modulation with the help of the auxiliary frequencies g_1 and g_2, we get, from the clear signal x, the coded signal z_c, the components of which are frequency-shifted. The degree of secrecy is insufficient as the frequency shift can be detected easily by experimentation.

by the difference of the two auxiliary frequencies. Even this frequency shift does not answer the practical demand as the necessary shift to reconstitute clear language can be found out too easily by experimenting.

To increase the secrecy, the spectrum of the voice frequencies is divided up into n bands, x_1 up to x_n, which, for transmission purposes, are shifted by unequal quantities. In this way, the m^{th} voice band x_m is shifted into the k_{th} voice band x_k. The key of this frequency shift is given by the relation between m and k, m giving the position of the original frequency band and k that of the displaced band. For example:—

m	k
1	3
2	4
3	1
4	5
5	2

It can be characterized by the number S which is obtained by the permutation of the normal succession 1, 2, 3, ... n. In our example S = 34152.

This substitution-keying is effected by the arrangement shown in Fig. 4. The first frequency band x_1 is transmitted through the band-pass filter F_1 to the modulator M_1 which modulates it with the auxiliary frequency g_1, given by the generator G_1. The sum frequency band y_1 belongs to the band that can pass through the band-pass filter BP and is transmitted to modulator N_3, for example. The difference-frequencies produced in this modulator constitute the third frequency-band z_3 of the codified signal, because only the differences can pass the low-pass filter TP. The other message frequency-bands are shifted in the same way. The frequency bands passing through the filters F_1, F_2, ... F_5, BP and the auxiliary frequencies $g_1 \ldots g_5$ of the generators G_1 and G_2 have, for example, the following values:

F_1	200 ÷ 750 cycles		g_1	3850 cycles
F_2	750—1300 "		g_2	4400 "
F_3	1300—1850 "		g_3	4950 "
F_4	1850—2400 "		g_4	5500 "
F_5	2400—2950 "		g_5	6050 "
BP	3100—3650 "			

The input filters $F_1 \ldots F_5$ can be suppressed, in certain cases, if the frequencies they should reject fall, after the first modulation, beyond the range of filter BP. The same device is used to reform the original message by a new frequency shift.

In Fig. 5 the first oscillogram represents the word "Gesellschaft", uncoded. Below it are represented separately, before the keying, the spectrums of the

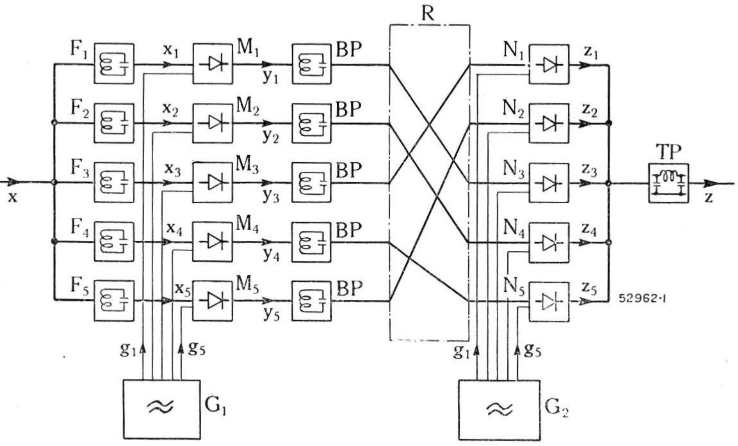

Fig. 4. — Substitution coding.

From double modulation with the auxiliary frequencies $g_1 \ldots g_5$ and signal-channel commutation in R, we get, from the original signal x, the coded signal z, the frequency bands of which are shifted by varying amounts. Undesired deciphering is difficult as the proper shift-back must be repeatedly searched for, for each one of its new values.

five frequency bands $x_1 \ldots x_5$ and, after the keying with key S = 34152, the bands $z_1 \ldots z_5 = x_{31} \ldots x_{45}$, the first index indicating the rank occupied before, and the second the rank occupied after the keying.

As the key S can easily enough be determined by tests, it is modified in the latest apparatus, at determined time intervals t_o. For this operation, the permutator R is used, which interchanges the five frequency bands according to a determined programme. This programme is given, for example, by the succession of the keys S_1 = 34152, S_2 = 51342, S_3 = 53421 etc. as in the following table:

m	k_1	k_2	k_3	k_4	k_5	k_6
1	3	5	5	1	3	4
2	4	1	3	4	2	5
3	1	3	4	5	4	2
4	5	4	2	2	1	3
5	2	2	1	3	5	1

The first band x_1 of the speech spectrum appears alternatively in the form of third, fifth, fifth, first, etc. frequency band x_{13}, x_{15}, x_{15}, x_{11}, of the coded signal z.

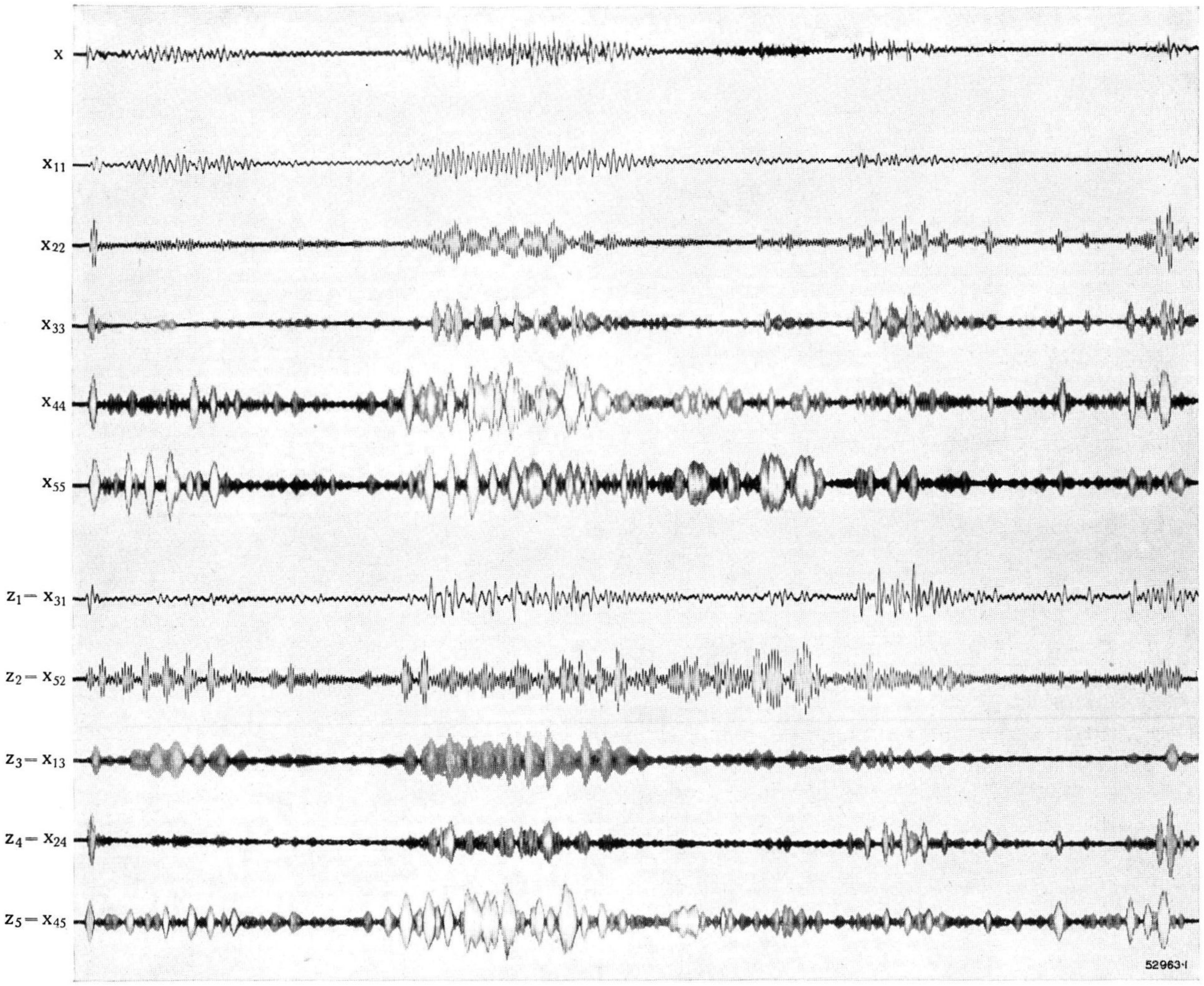

Fig. 5. — Substitution coding.

x. Clear signal oscillogram of the word "Gesellschaft". $x_{11} \dots x_{55}$. Oscillograms of the five frequency-bands of the word "Gesellschaft" $z_1 \dots z_5$. Oscillograms of the permutated frequency-bands, out of which the keyed signal is found.

By tests, the frequency-shift can be precisely determined. For example, one can see that the frequency-band z_4 is formed of the second clear message band x_{22}. For this reason, secrecy is limited.

The message to be transmitted x is subdivised into the successive elements a, b, c, ... of a duration t_o. Analogously, the spectrum in the first band x_1 is also divided into elements $a_1, b_1, c_1, \dots$, that of the second band into elements a_2, b_2, c_2, etc.

The message x can be represented as follows:

$$x = \begin{Bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \end{Bmatrix} = \begin{Bmatrix} a_1 & b_1 & c_1 & d_1 & e_1 & f_1 & g_1 & h_1 & i_1 & k_1 & \dots \\ a_2 & b_2 & c_2 & d_2 & e_2 & f_2 & g_2 & h_2 & i_2 & k_2 & \dots \\ a_3 & b_3 & c_3 & d_3 & e_3 & f_3 & g_3 & h_3 & i_3 & k_3 & \dots \\ a_4 & b_4 & c_4 & d_4 & e_4 & f_4 & g_4 & h_4 & i_4 & k_4 & \dots \\ a_5 & b_5 & c_5 & d_5 & e_5 & f_5 & g_5 & h_5 & i_5 & k_5 & \dots \end{Bmatrix}$$

In each line we find all the successive elements of one of the frequency bands; c_2, for example, is the third element of the second frequency band.

With the given keying programme, the transmitted signal z is represented as follows:

$$z = \begin{Bmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \\ z_5 \end{Bmatrix} = \begin{Bmatrix} a_{31} & b_{21} & c_{51} & d_{11} & e_{41} & f_{51} & g_{41} & h_{31} & i_{11} & k_{21} & \dots \\ a_{52} & b_{52} & c_{42} & d_{42} & e_{22} & f_{32} & g_{52} & h_{42} & i_{52} & k_{32} & \dots \\ a_{13} & b_{33} & c_{23} & d_{53} & e_{13} & f_{43} & g_{23} & h_{53} & i_{23} & k_{13} & \dots \\ a_{24} & b_{44} & c_{34} & d_{24} & e_{34} & f_{14} & g_{14} & h_{14} & i_{34} & k_{54} & \dots \\ a_{45} & b_{15} & c_{15} & d_{35} & e_{55} & f_{25} & g_{35} & h_{25} & i_{45} & k_{45} & \dots \end{Bmatrix}$$

In each line we find all the elements of a frequency band of the keyed message. The first index indicates from which frequency band of the original message the element is taken and the second into which frequency band the element has been shifted.

The interval between two key changes, that is the duration t_o of an element, is, in general, of a second or more. The deciphering of the received and recorded message is easily possible for an unauthorized listener. The often repeated spectrum of an element is taken from a frequency band and its frequency is shifted by a variable amount, until the unnatural impression produced by incorrect shifting disappears. It is possible to find out in the same way the shift of the other frequency bands of that element and of all the other following elements, which allows of reforming the clear language. This procedure gives remarkably quick results with a little training. The requisite time increases, however, when the element duration is reduced, it is, further, more difficult to find out the correct shift for short elements.

By a special synchronization system, we have been able to reduce the element duration to 0·05 s, which improves the secrecy of this substitution keying system considerably. Oscillograms obtained with elements having a duration of 0·03 s are reproduced in Fig. 6. The deciphering difficulties are also naturally increased if the number of frequency bands is increased and their width reduced at the same time; but this needs a greater number of filters and modulators. The use

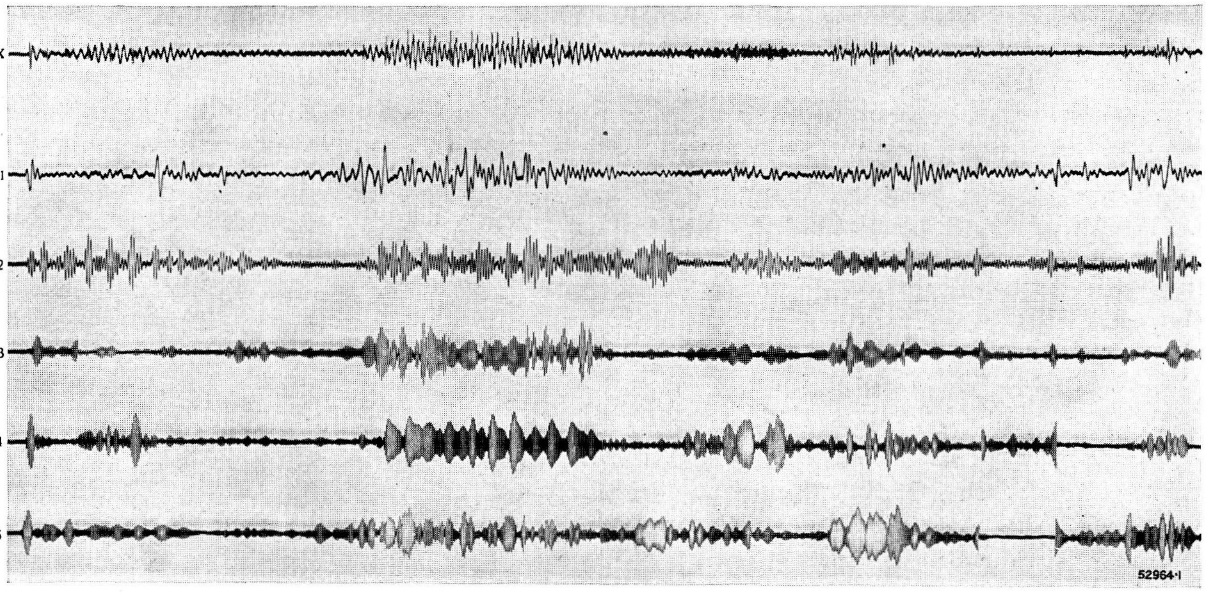

Fig. 6. — Substitution coding.

x. Oscillogram of the word "Gesellschaft". $z_1 \ldots z_5$. Oscillograms of the variably shifted frequency-bands of x.
Owing to the variable frequency shift, the correct back-shifting needed to decipher is difficult to find out and secrecy is thus considerably increased.

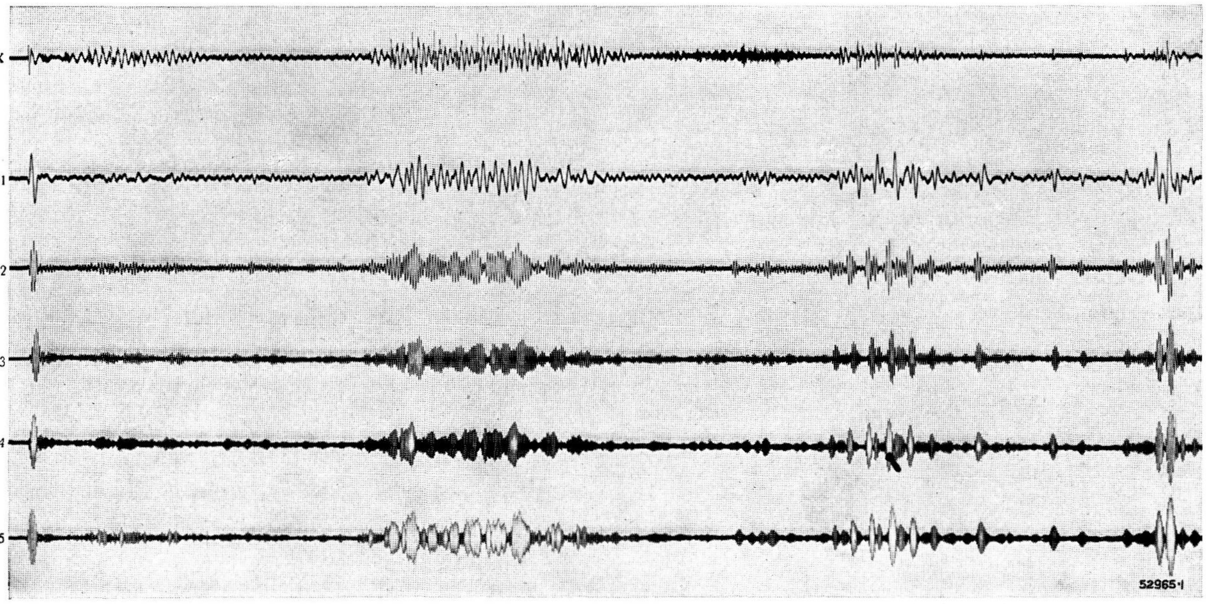

Fig. 7. — Frequency-band shifting.

x. Oscillogram of the word "Gesellschaft". $x_{21} \ldots x_{25}$. Second frequency band of x after having been shifted into the 5 frequency channels. It is clearly seen that the amplitude character is not altered by this frequency shift. Frequency-substitution scrambled signals can thus be deciphered by the analysis of the energy-rhythm.

of varying auxiliary modulation-frequencies g with continuously varying character also permits of replacing sudden frequency shifts by continuous ones.

The amplitude curve in function of time, $X_k = \sqrt{x_k^2}$ of each frequency band is not altered by the frequency shift. This is visible in Fig. 7, for example, where the spectrum of the second frequency band x_2 of the word "Gesellschaft" for several frequency shifts is reproduced. The sending sequence remains the same whatever the element duration and the amplitude diagram $Z_o\,(t) = \sqrt{z_1^2 + z_2^2 + \ldots}$ of the complete ciphered message z corresponds to the amplitude diagram $X_o\,(t) = \sqrt{x_1^2 + x_2^2 + \ldots}$ of the clear message. The characteristic fundamental frequency ω_o of keyed vowels can also be easily determined as it is the difference of the frequency shifted components of a band. For this reason, one can easily draw the melodic diagram $\omega_o\,(t)$ which gives the tone curve of the fundamental frequencies in function of time. The deciphering of the keyed message by unauthorized persons can be tried by comparison of the amplitude diagram $Z_o\,(t)$ and the melodic diagram $\omega_o\,(t)$ to known words and sentence diagrams. Although these diagrams depend greatly upon accent, pronounciation, etc., a systematic use of this method and a little exercise render possible the deciphering of substitution-keyed messages.

By a fairly simple method, we can complicate this deciphering, through weakening by unequal amounts the different frequency bands of the coded message before sending it. This modifies the amplitude diagram which can thus no longer be used for deciphering. These variations can easily be neutralized at the authorized receiver end by corresponding reduction of the damping of the different frequency bands, according to the programme agreed on in advance.

IV. TRANSPOSITION METHOD.

The initial successive message elements a, b, c ... of a duration t_o can be time-shifted by unequal amounts. According to a key $T = 41532$, the first element, for example, takes the forth place, the second the first place etc. so that to the original serie x, corresponds the serie z:

$$x = a\ b\ c\ d\ e$$
$$z = b\ e\ d\ a\ c$$

The realization of this transposition method is obtained by delaying the different elements by unequal time fractions, differing one from another by a whole multiple of t_o, before their transmission. As the delays cannot be negative, the overlined numbers will be increased by five units in the key $T = 4\bar{1}5\bar{3}\bar{2}$, from which the key $T^* = 46587$ results and the keyed message z^* will be:

$$z^* = \ldots a\ c\ b\ e\ d$$

In the device shown in Fig. 8 the elements are magnetically recorded on a steel band L, moving in the sense of the arrow, by the recorder magnets $K_1 \ldots K_5$. The pick-up magnet K_6 takes up the elements in their recording order and the eraser magnet K_7 neutralizes the message recording. For coding with the key T, the message oscillations, periodically returning, are successively sent to the horizontal conductors of the keying table Q, through the commutator U, turning in the direction indicated by the arrow, the diagonal conductors being connected to the recorders.

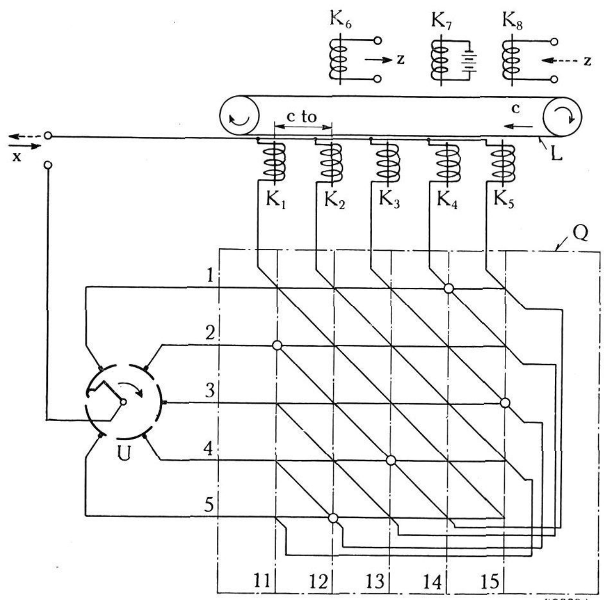

Fig. 8. — Transposition coding.

Through the commutator U and the keyboard Q the uncoded signal x is sent alternatively to one or the other of the recorder-magnets $K_1 \ldots K_5$ so that the elements are recorded in another order on the steel band L. The signal pick-up is carried out by K_6 and the erasing by K_7. For the decoding process, the signal is passed through the apparatus in the opposite direction (dotted arrow).

Connections between these conductors are indicated by small circles, corresponding to the key T, the first horizontal conductor being in contact with a diagonal conductor at it's forth crossing, the second at it's first crossing, etc. The first message element is recorded in forth place on the steel band for the original position indicated of the commutator switch. When the commutator has passed to the second contact, and the steel band has advanced an element length between two magnets, the second element is recorded in sixth position. After a complete revolution of the commutator, the five first elements are recorded on the steel band in the order of the keyed message z and are picked up by the magnet K_6. If the commutator and the band continue to advance, the same keying process is periodically repeated.

The keying must be chosen so that two elements are never recorded one on the other and that there is never a non-recorded gap on the steel band. The keyed message is then non-superimposed and without gaps. The study of a recording phase shows that this condition is fulfilled when, on each horizontal conductor 1 . . . 5 and on each vertical conductor 11 . . . 15, there is but one connecting point. This leads to the requirement that the key, as in the substitution method, be obtained by a permutation of a continuous serie of numbers 1, 2, 3, . . . n.

With a similar apparatus, the original message is given at the receiver end by a new permutation. The key T_e employed for this is a permutation of the series of numbers 1, 2, 3, . . . n, according to the key T used for the transmission. To the sending key T = 41532 or T* = 46587 corresponds the reception key T_e = 25413 or T_e^* = 25468. By keying with the sending key T* the element succession x = a b c d e becomes, for example, the transmitted signal y. After decoding with the key T_e^* at reception the signal x_e is obtained, which is retarded by five elements in respect to x:—

x	= a b c d e	
y	= . . . a c	b e d
x_e	=	a b c d e

In the decoding process, the coded signal is recorded by the recorder K_8. The elements, taken up by the pick-up magnets K_1 . . . K_5 and passed through the commutator U, reproduce the original message if the keys of both sender and receiver correspond.

With most keys, certain recorder or pick-up magnets are used several times, others not at all. The key given in Fig. 8 leaves, for example, magnets K_1 and K_2 unemployed. Certain magnets can, thus, be suppressed with a corresponding reduction of the number of possible key combinations.

The unauthorized listener can, by trying several key-settings, attempt to reconstitute a clear message. With the transposition method described, this process gives fairly quick results because of the frequent repetition of the same keying programme cycle.

A sufficient increase in the coding programme cycle is impossible with a single commutator, owing to the insufficient number of contact positions. On the transmitter side several pick-up magnets, can be used but in different number to that of the recorders. They are connected to the keying-table and to a commutator switch. For example, 10 recorders and 11 pick-up magnets give a cascade keying of a 110 element-period in the sent signal.

In Fig. 9 an oscillogram section is reproduced of the word "Gesellschaft" and below, the intermediate message y coded with the key T_s = 46587. The cascade coded message z results from a second keying given by the pick-up magnets connection order, according to key T_a = 437658.

Among the numerous possibilities to increase the period we shall also mention the use of perforated bands. Fig. 10 shows a device in which this principle is applied. A hole O_{nm} punched at the intersection of the n^{th} transversal line with the m^{th} longitudinal line of the band E corresponds to the m^{th} recording head and to the n^{th} element to be transmitted. As, until the recording moment of this element, the steel band has progressed by (n — 1) elements, the recording will take place at the $(n + m - 1)^{th}$ place on the steel band. The recording succession can be determined by the diagram on the right of Fig. 10. By drawing a horizontal line from the n^{th} element of the uncoded signal x to the hole O_{nm} and from this

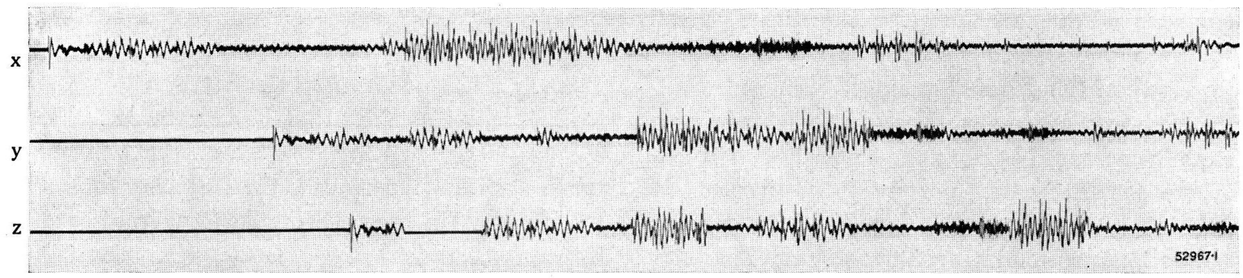

Fig. 9. — Transposition coding.
x. Clear signal oscillogram of the word "Gesellschaft". y. Intermediate signal after the first element shift.
z. Coded signal after the second element shift.
The shifting of all elements gives an incomprehensible signal. A possibility of undesired deciphering by back-shifting has however to be taken into consideration.

point by an oblique line, the $(n + m - 1)^{th}$ element of the coded message z is reached. Gaps and double recordings are avoided if there is but one hole on each horizontal and on each oblique line.

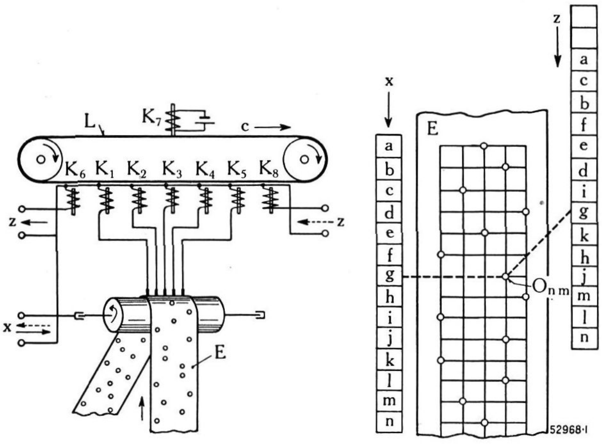

Fig. 10. — Transposition coding.

x. Uncoded signal. ——➤ Transmitting direction.
z. Coded signal. — — —➤ Receiving direction.

The shift of the message element is obtained by the alternate connecting (through the device of the perforated band E) of the recorder or pick-up magnets $K_1 \ldots K_5$. This system renders possible a big coding programme period and thus complicates undesired deciphering.

To control a large number of recording heads, combined hole-signs, comprising two or more holes on the same transversal line can be punched in the band, in which case an electric combiner is required. Here, the same measures to prevent unauthorized recording must be used.

The duration of a syllable of the German language, normally spoken, varies between 0·05 and 0·5 s. The duration of an element t_0 should be shorter than the duration of a syllable and the average element shift longer.

Practically the following values are used:

Element duration: 0·05 s.
Maximum delay: 0·8 s.

Based of these values, we have constructed coding apparatus which meet the given conditions perfectly well as to synchronization exactitude and the comprehensibility of the decoded message, even under unfavorable transmission conditions. The amplitude curve, which is unchanged by the normal substitution method is here completely transformed by the element permutation of the transposition method. An unauthorized decipherer, working on the energy rhythm analysis system, gets no results in this case. If the element shift is insufficient, one can however get an idea of the contents of the message by looking for the vowels of an element-group and in arranging them in a correct order which permits of finding out the words. An arbitrarily chosen decoding key sometimes allows of bringing back several elements to about their original order. With a little exercise, it is possible to guess the message words after a few deciphering tests with different keys.

The deciphering possibilities rapidly diminish with the increase of the element shift, but the increase of the shift increases, too, the duration of the transmission between the input of the coding apparatus and the output of the deciphering apparatus. This renders conversation difficult and consequently reduces the field of useful commercial application.

V. COMBINATION OF BOTH CODING METHODS.

The frequency band-substitution, as well as the transposition methods do not always satisfy the required conditions concerning secrecy. With the ordinary substitution method deciphering is possible by use of the amplitude and melodic diagrams, and the shifted elements of the transposition method can also be restituted to their initial order if their shifting time is too short. In both cases, the deciphering by someone not owning the key, requires great routine, an appropriate installation and much time.

For all cases in which the secret must absolutely be kept, even from well equipped deciphering specialists, we have elaborated a process which eliminates the inconveniences of both the above given methods.

From the initial signal x which, for example, has been divided into 5 different frequency bands $x_1 \ldots x_5$, and furthermore time-shifted, a signal z will result in which the original message will be both time-scrambled and frequency-shifted by varying amounts:

$$z = \begin{Bmatrix} z_1 \\ z_2 \\ z_3 \\ z_4 \\ z_5 \end{Bmatrix} = \begin{Bmatrix} \cdot & \cdot & a_{11} & b_{31} & c_{21} & e_{21} & f_{31} & f_{41} & h_{41} & g_{11} & g_{31} & \cdot & i_{41} & \cdot \\ \cdot & b_{22} & \cdot & a_{22} & a_{42} & c_{32} & g_{42} & h_{32} & e_{52} & k_{22} & h_{12} & i_{32} & \cdot & \cdot \\ a_{33} & \cdot & b_{53} & c_{43} & b_{43} & f_{53} & d_{23} & d_{33} & f_{13} & f_{23} & \cdot & \cdot & \cdot & k_{43} \\ \cdot & \cdot & \cdot & \cdot & d_{44} & d_{54} & e_{14} & g_{54} & g_{24} & i_{54} & i_{24} & h_{24} & k_{54} & \cdot \\ \cdot & a_{55} & c_{55} & d_{15} & e_{45} & b_{15} & c_{15} & e_{35} & i_{15} & h_{55} & k_{35} & k_{15} & \cdot & \cdot \end{Bmatrix}$$

The original successive news elements are again designated, here, as a, b, c.... The first index indicates the frequency band in which the element was before the keying and the second, the frequency band after the element has been shifted. As there is a frequency change (substitution) and a time-shift (transposition) we call this proceeding the combined method.

The new coding is realized by the use of various intermediate signals. A first intermediate signal is obtained, for example, by frequency-shifting the five frequency-bands $x_1 \ldots x_5$ into a same frequency band, indicated by index 6:

$$y_a = \begin{Bmatrix} y_{a_1} \\ y_{a_2} \\ y_{a_3} \\ y_{a_4} \\ y_{a_5} \end{Bmatrix} = \begin{Bmatrix} a_{16} & b_{16} & c_{16} & d_{16} & e_{16} & f_{16} & g_{16} & h_{16} & i_{16} & k_{16} \\ a_{26} & b_{26} & c_{26} & d_{26} & e_{26} & f_{26} & g_{26} & h_{26} & i_{26} & k_{26} \\ a_{36} & b_{36} & c_{36} & d_{36} & e_{36} & f_{36} & g_{36} & h_{36} & i_{36} & k_{36} \\ a_{46} & b_{46} & c_{46} & d_{46} & e_{46} & f_{46} & g_{46} & h_{46} & i_{46} & k_{46} \\ a_{56} & b_{56} & c_{56} & d_{56} & e_{56} & f_{56} & g_{56} & h_{56} & i_{56} & k_{56} \end{Bmatrix}$$

Another intermediate signal is obtained by alternatively exchanging the five signal channels:

$$y_b = \begin{Bmatrix} y_{b_1} \\ y_{b_2} \\ y_{b_3} \\ y_{b_4} \\ y_{b_5} \end{Bmatrix} = \begin{Bmatrix} a_{36} & b_{26} & c_{56} & d_{16} & e_{46} & f_{56} & g_{46} & h_{36} & i_{16} & k_{26} \\ a_{56} & b_{56} & c_{46} & d_{46} & e_{26} & f_{36} & g_{56} & h_{46} & i_{56} & k_{36} \\ a_{16} & b_{36} & c_{26} & d_{56} & e_{16} & f_{46} & g_{26} & h_{56} & i_{26} & k_{16} \\ a_{26} & b_{46} & c_{36} & d_{26} & e_{36} & f_{16} & g_{16} & h_{16} & i_{36} & k_{56} \\ a_{46} & b_{16} & c_{16} & d_{36} & e_{56} & f_{26} & g_{36} & h_{26} & i_{46} & k_{46} \end{Bmatrix}$$

By delaying unequally the different individual bands, a third intermediate signal is produced:

$$y_c = \begin{Bmatrix} y_{c_1} \\ y_{c_2} \\ y_{c_3} \\ y_{c_4} \\ y_{c_5} \end{Bmatrix} = \begin{Bmatrix} a_{36} & b_{26} & c_{56} & d_{16} & e_{46} & f_{56} & g_{46} & h_{36} & i_{16} & k_{26} & . & . & . & . \\ . & a_{56} & b_{56} & c_{46} & d_{46} & e_{26} & f_{36} & g_{56} & h_{46} & i_{56} & k_{36} & . & . & . \\ . & . & a_{16} & b_{36} & c_{26} & d_{56} & e_{16} & f_{46} & g_{26} & h_{56} & i_{26} & k_{16} & . & . \\ . & . & . & a_{26} & b_{46} & c_{36} & d_{26} & e_{36} & f_{16} & g_{16} & h_{16} & i_{36} & k_{56} & . \\ . & . & . & . & a_{46} & b_{16} & c_{16} & d_{36} & e_{56} & f_{26} & g_{36} & h_{26} & i_{46} & k_{46} \end{Bmatrix}$$

Finally, the signal y_d is obtained from y_c by a new permutation of the channel order:

$$y_d = \begin{Bmatrix} y_{d_1} \\ y_{d_2} \\ y_{d_3} \\ y_{d_4} \\ y_{d_5} \end{Bmatrix} = \begin{Bmatrix} . & . & a_{16} & b_{36} & c_{26} & e_{26} & f_{36} & f_{46} & h_{46} & g_{16} & g_{36} & . & i_{46} & . \\ . & b_{26} & . & a_{26} & a_{46} & c_{36} & g_{46} & h_{36} & e_{56} & k_{26} & h_{16} & i_{36} & . & . \\ a_{36} & . & b_{56} & c_{46} & b_{46} & f_{56} & d_{26} & d_{36} & f_{16} & f_{26} & . & . & . & k_{46} \\ . & . & . & . & d_{46} & d_{56} & e_{16} & g_{56} & g_{26} & i_{56} & i_{26} & h_{26} & k_{56} & . \\ . & a_{56} & c_{56} & d_{16} & e_{46} & b_{16} & c_{16} & e_{36} & i_{16} & h_{56} & k_{36} & k_{16} & . & . \end{Bmatrix}$$

The individual bands of y_d, are now back-shifted into the voice frequency-band by an unequal frequency-shift and thus the keyed signal z is produced, which can be transmitted by a standard speech-frequency band.

The deciphering of the message by displacing the elements is now impossible because of the frequency-change. The dephasing of the elements deforms the energy diagram used for the deciphering of ordinarily substitution-method messages. The two dangerous deciphering possibilities are thus eliminated by this proceeding.

Fig. 11 shows a device for combined keying. $M_1 \ldots M_5$ are the modulators to form the difference-frequencies from the original message and from the auxiliary frequencies produced by the generator G. The intermediate signal y_a is formed by filtering through the filters BP the 3100—3650 cycle frequency band of the modulation product.

The frequency-shifted bands are now permutated by the permutator switch Q, the output result of which are the five frequency bands $y_{b_1} \ldots y_{b_5}$ composing the signal y_b. These five frequency bands are next sent through a 5 channel retarding steel band-device $H_1 \ldots H_5$ ensuring by a single motor drive an equal element delay time t_o on each channel. At the pick-up magnets $K_1 \ldots K_5$, the five parts $y_{c_1} \ldots y_{c_5}$ of the intermediate signal y_c are obtained. One can, if it is desired, send each part through a band-pass filter ZP which suppresses all disturbing frequencies situated outside of the band. A new element-permutation by the permutator switch P gives the intermediate signal y_d and, by a second modulation with auxiliary frequencies $g_1 \ldots g_5$, the message z, covering all the 200÷2950 cycles frequency band, is obtained. The sum-frequencies engendered in modulators $N_1 \ldots N_5$ are superior to 6950 cycles and are withheld by the collective low-pass filter TP.

For deciphering, the signal passes the same way through the apparatus, it is only necessary to invert the drive of the permutator switches P and Q. The drive of the receiving permutator P must however be delayed in respect to that of the sending permutator Q, by a time corresponding to the time required for each element to pass through both apparatus. This passage-time, contrarily to that which is needed in

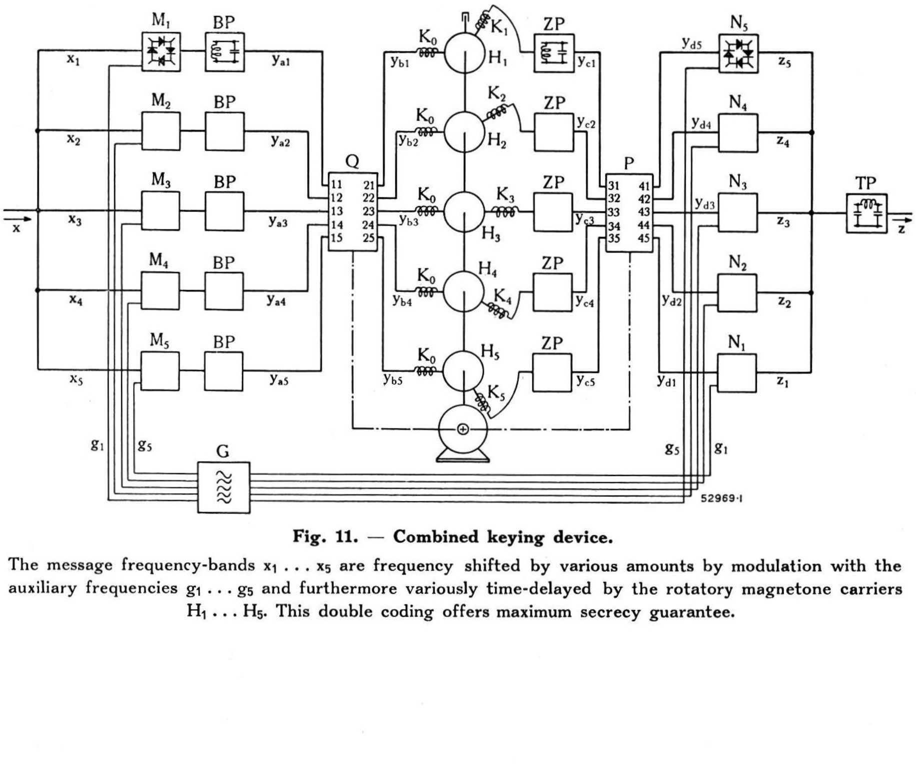

Fig. 11. — Combined keying device.

The message frequency-bands $x_1 \ldots x_5$ are frequency shifted by various amounts by modulation with the auxiliary frequencies $g_1 \ldots g_5$ and furthermore variously time-delayed by the rotatory magnetone carriers $H_1 \ldots H_5$. This double coding offers maximum secrecy guarantee.

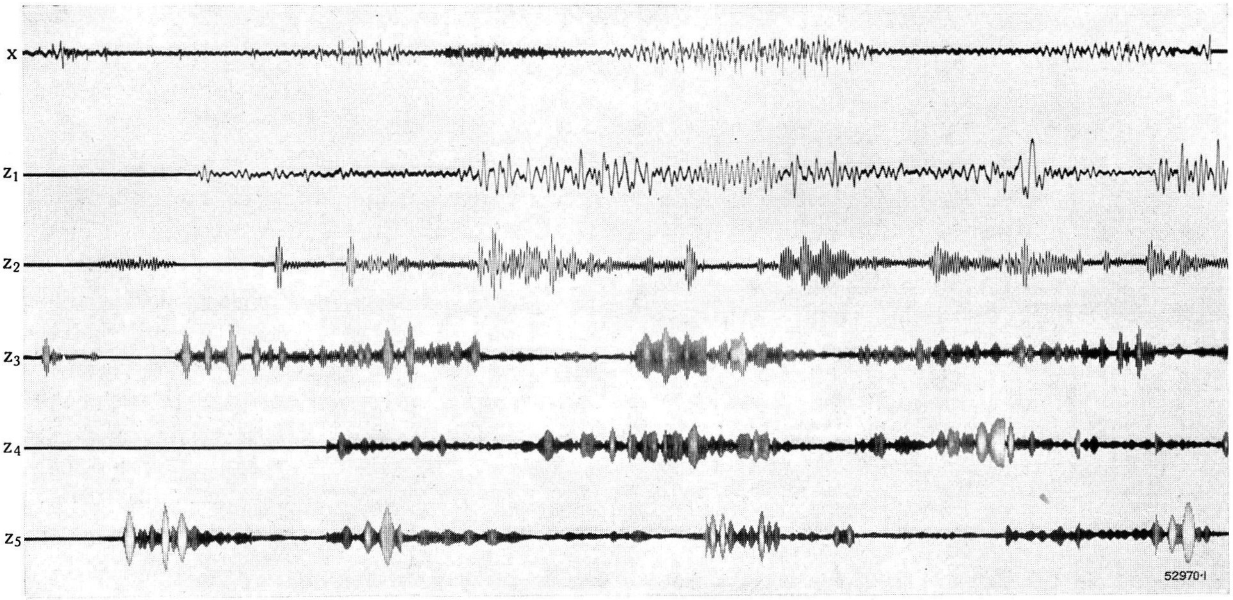

Fig. 12. — Combined coding.

x. Uncoded signal oscillogram of the word "Gesellschaft". $z_1 \ldots z_5$ Coded signal frequency bands, time and frequency shifted by variable amounts. The characteristics of the fundamental signal x are no longer recognizable on the delayed and frequency-shifted bands $z_1 \ldots z_5$. Any deciphering without knowing the key is practically impossible.

the substitution method, may be short and conversation is thus not impeded.

In Fig. 12 the frequency bands $z_1 \ldots z_5$ of the signal z are represented below the voice oscillogram x which has been obtained by 0·03 s element combined-keying.

VI. TRANSMISSION OF CHARACTERISTIC VALUES.

Efficient coding is also attained if, instead of transmitting modified or shifted voice frequencies, this is performed with characteristic values of the amplitude spectrum. For high fidelity transmission it would be necessary to transmit an incommensurable number of characteristic values, corresponding to the great number of variable partial amplitudes and their dephasing.

It is preferable to determine the variable fundamental frequency of the vowels and the amplitudes of a great number of voice frequency-bands by means of automatic voice-analysis. For the transmission of the corresponding characteristic values, a finite number of transmission channels is sufficient, the total band width of which is even slightly smaller than that of the normal voice range.

To reproduce the voice at the receiver, a blend of oscillations is made, the vowel fundamental-frequency of which is synchronized with the fundamental frequency of the transmitter. For consonants, the oscillation has, as on the transmitter-side, a noise-character.

By means of the particular amplitude characteristics, the frequency-bands of this oscillation blend are controlled in such a manner that the amplitude depending on the frequency approximates at least to that of the initial message.

In this way, vowels and consonants having no coincidence with the clear voice signal x, are produced. They are, nevertheless, comprehensible because their oscillation character and the energy distribution of the spectrum approach those of the clear signal.

The realization of the characteristic-values method is simplified if, already on the transmitter side, the vowel oscillation g and an oscillation blend h of a frequency band of small width got out of the consonants is transmitted to the receiver through a special channel. The oscillation blends v_o and w_o respectively are produced from the signals g and h, at the reception end, by non-linear transmission. These blends v_o and w_o are formed, one of the high harmonics of g having a tone character and the other of an unlimited number of partial vibrations having a noise character. From these oscillation blends, comprehensible spoken words or sentences can be reconstituted by amplitude-controlling the separate frequency bands in function of the characteristic values.

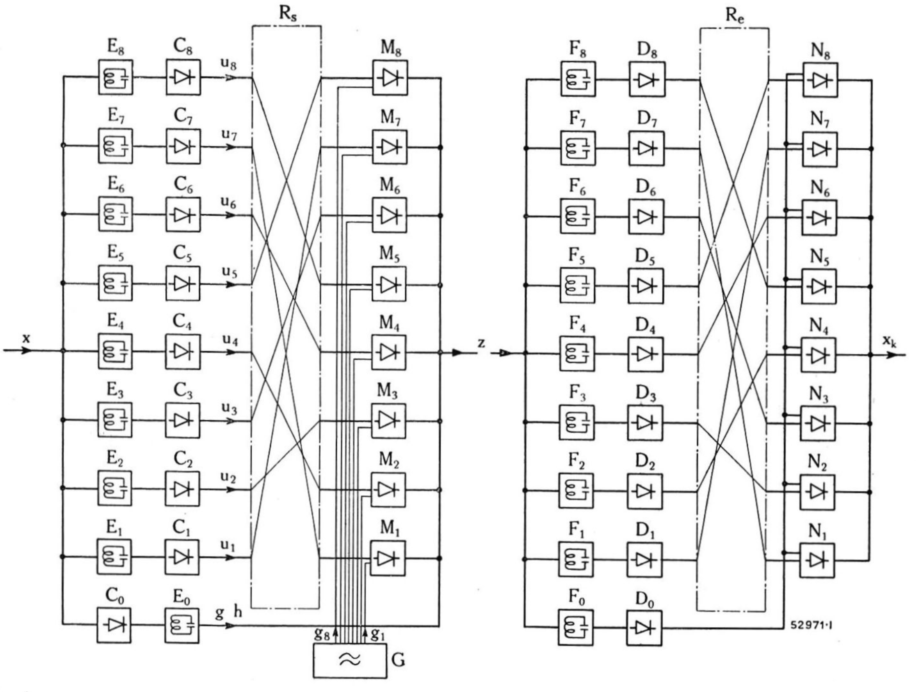

Fig. 13. — Characteristic-values coding.

The characteristic values $u_1 \ldots u_8$, which characterize the amplitude spectrum of the uncoded signal x, are variably shifted on the transmitter side by the permutator R_s and brought again to their original order on the receiver side by the permutator R_e, thus reproducing the uncoded signal x_k.

In the keying device shown in Fig. 13, the non-linear transductor C_o and a low pass filter E_o, to extract respectively g and h are coupled on the transmitter end. By filtering the spectrums of the different frequency bands, $E_1 \ldots E_8$ and in demodulating them in $C_1 \ldots C_8$, the characteristic values $u_1 \ldots u_8$ are obtained. To transmit these values through a channel, they are modulated in the modulators $M_1 \ldots M_8$ with the low carrier frequencies $g_1 \ldots g_8$, produced by the generator G.

At reception, the characteristic values are reconstituted by elimination of the carrier waves in the band filter $F_1 \ldots F_8$ and by demodulation in $D_1 \ldots D_8$. At the output of the low pass filter F_o, the oscillations g and h appear, forming the oscillation blend composed of v_o and w_o respectively, which are carried through the non-linear link D_o. The speech constituting frequency bands now appear, by amplitude-control with the slow changing characteristic values $u_1 \ldots u_8$, in the modulators $N_1 \ldots N_8$.

An unauthorized listener, with an appropriate receiver could, nevertheless, tap an understandable message. For this reasons, the permutators R_s and R_e, which continually change the connecting order of the signal channels, keying the message at the sender side and unkeying it at the receiver side, are inserted in the device. In place of this channel permutation, a transposition coding of the characteristic values with a variable time delay, could be used.

Finally, the characteristic values can be simultaneously permutated and delayed. This characteristic-value coding, by substitution, transposition or combined method is realized by the apparatus already described.

The synchronous drive of the sender's keying switch and the receiver's unkeying switch is ensured by our synchronization system, which has been proved efficient even for very rapid communications.

Although speech, transmitted by the characteristic-values process, is comprehensible, certain finesses are lost, as both analysis and synthesis are accomplished with a comparatively small number of frequency bands.

VII. CODING PROGRAMME AND SYNCHRONIZATION.

In the coding systems described (substitution, transposition, combined and characteristic-values processes) the signal channels or message elements are permuted in accordance with a given key which is periodically varied to ensure a better secrecy.

These changes are effected according to a programme agreed on between the transmitter and the receiving stations. The different keys can be recorded on perforated paper bands. This offers various advantages as compared to other systems. The bands can be pasted end to end so as have any length desired and the period when a given programme is valid can thus be chosen as desired and the changes are unknown to the unauthorized listener. This complicates considerably any unauthorized deciphering. This perforated band is easy to establish, the holes corresponding to the desired commutation programme being simply punched in it with the perforator. It also is of little weight and can be easily changed or destroyed if necessary.

Each hole combination of a band is generally in direct correlation to a key but two or more bands can also be read simultaneously, each combination of signs corresponding to a certain key. If the bands do not have the same number of holes, the period of the total coded programme is very long. Element-shift and channel selection are realized in band-commutation by the usual methods. The key-changing in both transmitter and receiver must, of course be simultaneous; a perfect synchronization on both sides is of highest importance. Serious tests have shown us that with 0·05—0·1 s elements, synchronization errors of 5 % of the element length have already a perturbating effect and that for errors of 10 % comprehensibility is considerably reduced. For this reason we have realized a synchronization system, assuring an exactitude of 1 to 2 % of the element length, that is of a $^1/_{1000}$th s. The synchronization subsists even when transitory interferences or interruptions of a duration of up to 0·5—1 min. occur in the transmission. This means that deciphering is not put out of order by the poorest transmission conditions.

VIII. PRACTICAL APPLICATIONS OF THE VOICE-SCRAMBLING METHOD.

Choice of a voice-scrambling method is subordinated to the condition of each particular case. The substitution method known and used since some years has been considerably improved by our synchronization device which has permitted a reduction of the element duration. It is suitable for cases in which attempts at unauthorized deciphering, which, as a matter of fact, require great routine and complicated apparatus, are not to be feared. With the transposition method secrecy can be increased at the expense of longer transmission time. Conversation is, however, rendered more difficult in this way and this prevents the generalization of this method for commercial use. The apparatus size and weight are however less than those of the substitution apparatus because of the suppression of filters. The transposition method is thus particularily suitable for portable apparatus, when certain concessions can be made as regards duration of transmission and degree of secrecy. In the cases where maximum secrecy is essential, the combined method is preferred because attempts at unauthorized deciphering, which had given successful results when tried with the substitution and transposition methods, failed to do so here. As it is possible to work with very small delays, combined keying is especially convenient for commercial use. Message transmission by the characteristic-values coding system has the advantage of offering a good utilization of the transmission channel with a maximum degree of secrecy. The tone of voice is slightly altered, in this case, however.

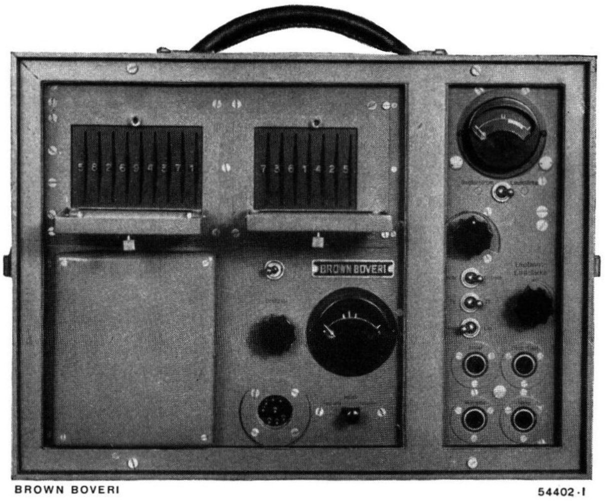

Fig. 14. — Portable coding and decoding apparatus.
The ciphers are set by means of selector switches. This simple and easily run apparatus weighs only 23 kg (51 lbs). Secrecy is, however, limited.

In many cases, the scrambling apparatus is used to code non vocal signals, for example morse telegrams. Transposition or combined coding can be directly used for this purpose. The substitution method requires some auxiliary apparatus. A single keying device enables the simultaneous coding of several messages sent through different telegraphic transmission channels.

Fig. 14 shows a portable keying apparatus with it's supply equipement. This apparatus can be used both for coding or decoding spoken or telegraph-transmitted messages. The communication inversion is obtained by a simple actuating of a push-button switch placed on the micro-telephone device. The key is a number composed of several figures. For telegraphic messages a morse key can be connected. The apparatus uses the transposition method and has given good results in severe tests. The speech intelligibility at reception is particularly good.

The secrecy ensured by this relatively simple kind of apparatus meets nearly every requirement. It is superior to that of most of the well-known commercial devices which are many times it's size. We have begun the construction of larger apparatus, utilizing here the same effective principles which assure a maximum of secrecy.

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MODERN POLICE WIRELESS.

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Attention is drawn, in this article, to the strenuous demands which a modern police organisation makes on the technical means of communication at its disposal. Here, it will be shown that the police wireless system developed by Brown Boveri has great advantages as compared to earlier equipments, as two different wave bands are made use of for conversations, one of which is operated by frequency modulation. On the other hand, reference is made to ultra-short wave receivers the switching on and off of which is carried out through the automatic telephone system.

THE efficiency of a police force depends not only on the sound technical training of each member of the staff, but also on a number of auxiliary sources of assistance. Modern engineering has made these available to the criminal investigation department; to-day's methods of detection are based to a great extent on a smoothly working information service which, up till quite lately, was mainly dependent on communications by wire.

Wireless has already been used to render detection more reliable, but the operation of most of these wireless equipments proved to be too complicated and their performance was often impaired by their being liable to breakdowns. Moreover, their use was based on the assumption that every member of the police force had a certain amount of special technical knowledge and this among other reasons explain why, in many police forces, wireless did not have the success predicted for it.

Brown Boveri have followed, in various respects, fundamentally new methods in developing their police wireless system, with the view to simplify the equipment in such a way that operation and maintenance would become as easy as in an ordinary telephone plant. As a result, such a high degree of reliability is obtained under all conditions that the system works even when the operator is completely absorbed by his specific tasks as a member of a police force and is, thus, unable to give his attention to the coaxing of delicate equipment to make it work. Some of these apparatus are described in detail in the following paragraphs, they have been developed and produced to fulfil the requirements of a modern police force directed from headquarters.

Fig. 1 shows diagrammatically a modern police wireless system of the kind in question. It consists of a *transmitter and receiving unit* at headquarters. The transmitter is designed for remote operation, the operator's office being equipped with the necessary remote control and auxiliary devices. The *mobile transmitters and receivers* have to work under very strenuous conditions. They may be mounted in police patrol cars, motor boats, or other vehicles belonging to flying squads. There are, also, light weight *portable receivers* with an automatic calling device, which are slung on a strap over the shoulder of police officers.

If the topographic configuration of the country impairs reliable communication between the mobile stations and headquarters, *remote-controlled receivers* are utilized. These are mounted on the top of the obstacles to enable the whole area of service to be covered.

The Brown Boveri police wireless system permits automatic selective calling of different groups of mobile or portable stations. Calling the mobile road patrols is effected by transmitting a continuously modulated carrier, while the portable sets are alarmed by the carrier itself.

As a matter of fact, the organization of criminal investigation services has often to be changed on the account of the continual expansion of cities. To prove of real value to a police force, the fixed and mobile equipments must be designed so that they can be used anywhere and adapted, later, to new or extended working conditions, without great change or cost.

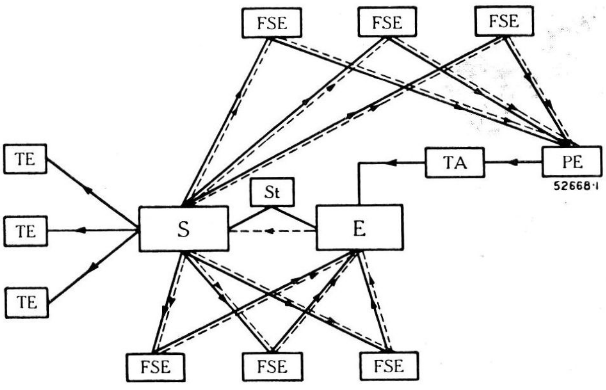

Fig. 1. — Diagrammatic representation of a modern police wireless organisation.

—— > —— Communication between controlling station and mobile and portable stations.

·····>····· Communication between mobile stations either through remote receivers or directly through the wireless controlling station.

S. Transmitter.
E. Receiver.
TE. Portable receivers.
PE. Remote receivers.
FSE. Mobile transmitters and receivers.
TA. Telephone central station.
ST. Remote-control device.

This diagram shows what numerous connections are possible, these embrace practically every branch of a police organisation.

One of the most modern headquarters equipments, which was developed in our laboratories and which is actually working in one of Switzerland's biggest towns, where there is a very efficient police force, covers a wave range of 110—220 m. In this band three fixed and one continuously variable wave may be instantly selected by means of push-buttons. This combination of frequencies permits maximum flexibility and reliability in service because, in case of emergency, the variable wave can be brought into action as a stand-by wave, for one of the three fixed waves, within a few minutes.

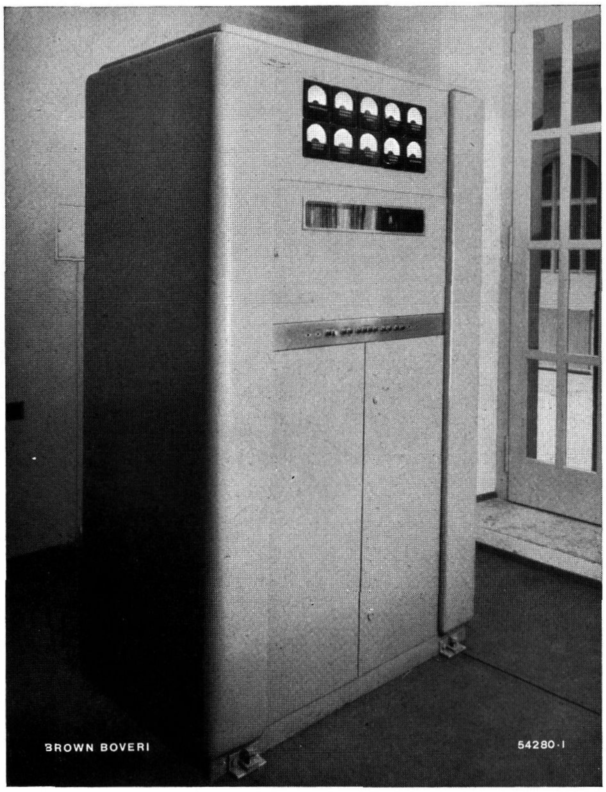

Fig. 2. — 500-watt police transmitter for telephony and modulated carrier-wave telegraphy.

Power adjustable in three steps to 125, 250 and 500 watts. Wave range 110 to 220 m with three fixed waves chosen as desired and one variable wave. The totally enclosed design gives a compact and pleasing appearance to the transmitter cabinet. It also contains all auxiliary apparatus for direct connection to a three-phase system, besides all the transmitting and modulating parts.

Fig. 2 shows the headquarters transmitter. The power output of this unit naturally depends upon the kind of service and the area to be covered. The operator can select three different stages of power output between 125 and 500 watts. If the transmitter is needed for different services, to each is allocated a wave-length best suited to its requirements. One of the fixed waves may for instance be adjusted to the wave-length of the local broadcasting station. Thus, in case of emergency, the police headquarter station can replace the local broadcasting station. Another fixed wave may be reserved for the specific police requirements and a third one may be used by the headquarters of the criminal investigation department and fire brigade, for alarming purposes. The fourth variable wave is a stand-by wave or it may be used for special remote control work, such as is frequently required in modern days for the transmission of black-out or A. R. P. orders. The transmitter can be fully controlled from the transmitting room itself, or remotely from an operator's table in one of the rooms at headquarters. By means of a suitable amplifier, modulation over a two-wire post-office line is possible from any distant studio room. Should the transmitter have to replace the local station, broadcasting quality must be maintained. All parts are, therefore, conservatively designed. The maximum distortion factor, for instance, does not exceed 3 % for full modulation of 100 %. For special police requirements this high degree of quality is not necessary. In this case a special filter network is switched into the modulation channel to cut off the lower frequencies in order to increase the intelligibility of speech.

Operation and control of all the apparatus belonging to extensive installations, such as this, is effected from one central point at headquarters.

Fig. 3 shows the interior of a dispatcher's room of the kind in question. There is a microphone and a remote control equipment on the operator's table. This apparatus enables the operator, by means of pilot lamps, to supervise continuously the whole installation and to control remotely not only decentralized transmitters, but also distant receivers. By means of selector switches he calls certain groups of mobile and portable stations or he enables mobile stations to communicate directly with any telephone subscriber. He also effects the necessary switching if two mobile stations desire to communicate with one another while *running on the road.*

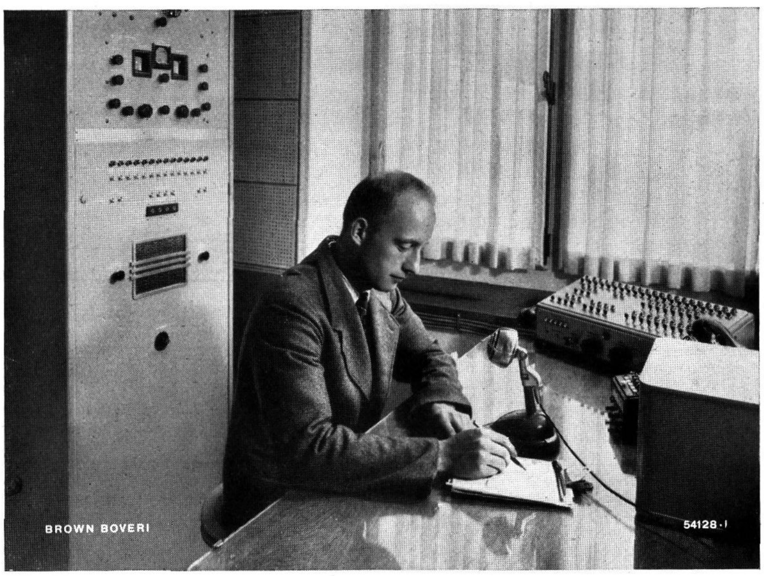

Fig. 3. — Interior of a modern police wireless controlling station.

Left: Receiver frame with auxiliary apparatus.

Right: Microphone, control and supervisory equipment, telephone line-selector and controlling loud speaker.

The practical layout of the equipment allowing the operator to work quickly is very striking. He can reach all switches and buttons which he has to manipulate from his seat without difficulty.

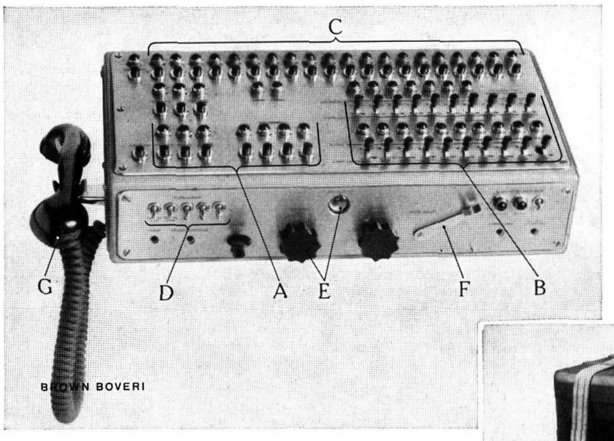

Fig. 4. — Controlling and supervising equipment.

A. Control switches for the headquarters transmitter.
B. Lever switches for changing over incoming lines and signals to the transmitter; also for remote control of the remote receivers.
C. Signal lamps to indicate selective calling up of mobile stations.
D. Switches for selective calling up of groups.
E. Control of modulation.
F. Selector switch for the remote controlled ultra short-wave receivers.
G. Micro-telephone.

This is the brain of the whole plant. Here about 300 control and supervision lines converge. One glance suffices to inform the operator of the actual service condition of the entire police wireless organization.

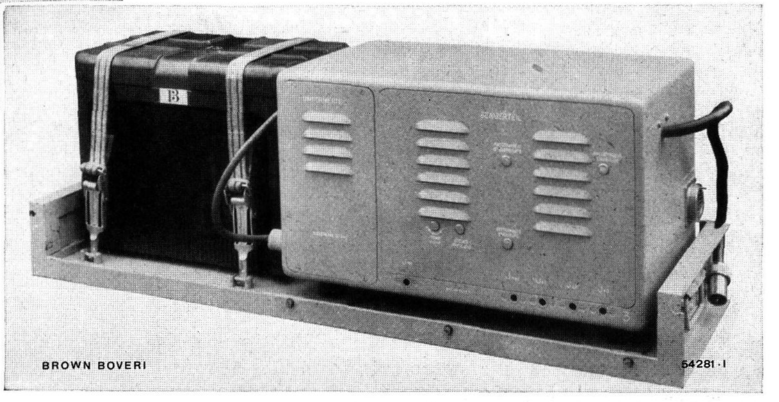

Fig. 5. — Mobile ultra short-wave transmitter with frequency-modulation, output 10 watts, with supply storage battery 105 Ah, mounted on a portable frame.

The compact, strong design is very noticeable. The mounting on a frame allows quick interchanging from one car to another of a police wireless organization.

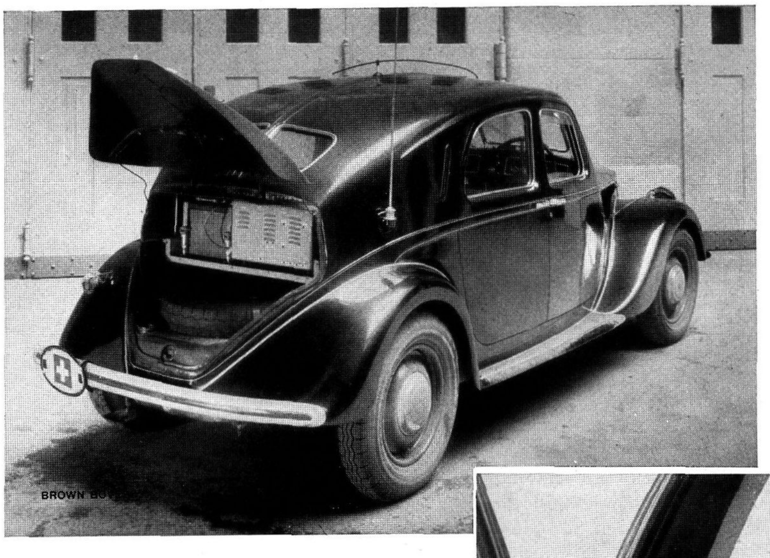

Fig. 6. — Police patrol car with ultra short-wave transmitter built into the luggage holder, with rod transmitting aerial and short-wave receiving aerial on the roof.

The aerial layout is made to suit the external appearance of the car as well as possible and really is very unnoticeable. Thanks to a compact design, it is possible to find room for the transmitter in even the smallest luggage holder.

Fig. 7. — Mobile short-wave receiver and control equipment in the driver's seat of a police patrol car.

It comprises a short-wave receiver with loud speaker and micro-telephone, control buttons for the remote control of the transmitter part as well as a device for passing automatic calls. Here, also, the dimensions of the equipment are reduced to a minimum because experience tells that there is never too much space available in the driver's seat of a police car. In the layout of the signalling and operating buttons, special care has been given to making them as accessible and as easy to supervise as is possible.

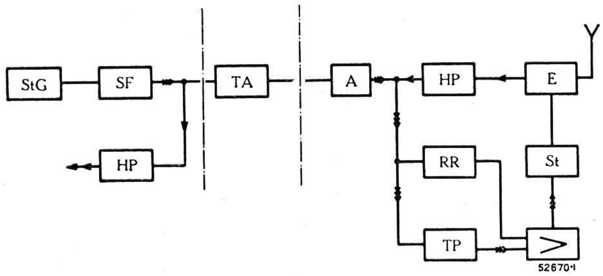

Fig. 8. — Fundamental diagram for the remote control of an ultra short wave receiver which can be switched in through a telephone line.

Transmitting station:		Receiving station:	
St.	Controlling device.	H. P.	High pass filter.
StG.	Control generators.	T. P.	Low pass filter.
SF.	Transmitting filter.	E.	Receiver.
TA.	Telephone station.	RR.	Calling relay.
A.	Matching.	Fk.	Headquarters.

>. Amplifier.

As the diagram shows, the control device developed by Brown Boveri operates with a minimum of switching elements, in consequence we get excellent efficiency and good transmission qualities.

An interesting point about the mobile stations is that this is the first time *frequency modulated ultra-short waves* are used in Europe for communication purposes. Numerous measurements and tests have proved this kind of wave to be particularly suitable for wireless communication in towns where electric interference from motor-car ignition and X-rays apparatus is very frequent. Compared with the well known amplitude modulation system, the new method shows a far better ratio of signal strength to noise.

Fig. 9. — Policeman with short-wave super-regenerative receiver slung over his shoulder.

Battery, aerial and call-up device are built into the receiver. The latter is a fine technical achievement as all switching elements besides the source of power are lodged in a very small space. The illustration shows clearly that the man is not impeded by the equipment from carrying out his duties.

Regarding propagation properties, it has been found that this special kind of wave can be used to great advantage even in towns with numerous obstacles, without impairing the high degree of performance, which can easily compete with that of normal telephone lines.

As a matter of fact, mobile stations have to work under very adverse conditions because police patrol cars often move with great speed over very rough roads. The mobile transmitter is lodged, together with a low-voltage battery in a welded frame, which is mounted in the patrol car. The short wave receiver with built-in automatic calling device is fixed in front of the driver on the dash board. It is of very small size and light in weight, to meet the demand of mobile police work. The police forces, generally, possess different types of vehicle and the construction shown in Fig. 5 enables parts of the whole equipment to be interchanged within a few minutes.

The remote-controlled receivers, which are generally placed in the suburbs of large towns, are operated by a new Brown Boveri system. Switching on and off, as well as tuning, is effected over a normal telephone line, preliminarily switched in by an automatic telephone selector. Low-frequency oscillators, which are placed in the headquarters station, produce control voltages of different frequencies which reach the remote receiver over the line through different low-frequency filter networks. These control voltages operate remote relays which act upon the receiver. When all traffic has ceased, the remote receivers and the lines are automatically switched off. The performance of this new system is extremely good and precautions have been taken to prevent interference by unauthorized persons from outside.

A modern police organisation must provide for the calling of every member of the police force at any moment. This is of special importance in case of emergency. For this purpose every policeman is equipped with a light-weight portable receiver. This set is of the super-regenerative type and possesses an extremely high sensitivity. A built-in automatic calling device enables the wearer of the set to be alarmed within a radius of 6 miles from the headquarters' transmitter.

Flying patrols on motor-cycles may also be equipped to great advantage with the same type of set. Thus they, too, remain continually in contact with headquarters.

A police force, which has availed itself of this latest advance in the high-frequency field, will certainly show maximum efficiency in emergencies.

(MS 815) *A. Wertli.*

PORTABLE MILITARY WIRELESS EQUIPMENTS.

Decimal index 621.396.99 : 623

The various properties required of military transmitting and receiving sets, from the electrical and mechanical point of view, are set out here. It is shown that a relatively complicated design is needed to meet the requirements in question and that it must follow the lines of aeronautical construction in order to attain the lowest weight and smallest dimensions. A portable equipment built by Brown Boveri, which is self-contained, is described here and illustrated.

IT is hardly necessary to stress the importance of wireless telegraphy and telephony in modern armies. Events have shown sufficiently clearly that efficient information facilities are a factor of vital importance.

For military purpose, the main interest is concentrated on wireless equipments which are self-sufficing and very portable while being mechanically strong and up to date from the electrical point of view. Further, simplicity in operation, easy detection of the source of any trouble and facility in repairing are qualities which are much appreciated in military equipments.

If these requirements are examined more closely, it will be seen that they are, for the greater part, contradictory. Thus, a 6-valve super-heterodyne receiving set of great sensitivity, selectivity and high fidelity is certainly more liable to trouble and is heavier than a one-valve audion or super-regenerative receiving set. The same applies also to a 7-valve transmitting set for c.w. or i.c.w. telegraphy and for telephony with cristal microphone, in comparison to a 1-valve transmitter with carbon microphone. It would appear, according to this, that a one-valve transmission-reception set should be the ideal solution for a military wireless equipment. As a matter of fact, an apparatus like this would be exceptionally light, but its electrical performance would be quite insufficient and could not be conciliated with the present-day level of technical development. Thus, there is no escaping from the necessity of utilizing a high-class transmitter and receiver of relatively complicated design and of making these so compact that dimensions and weight are both very low. This result can only be attained by using the best materials and following the constructive lines used in aeronautical design.

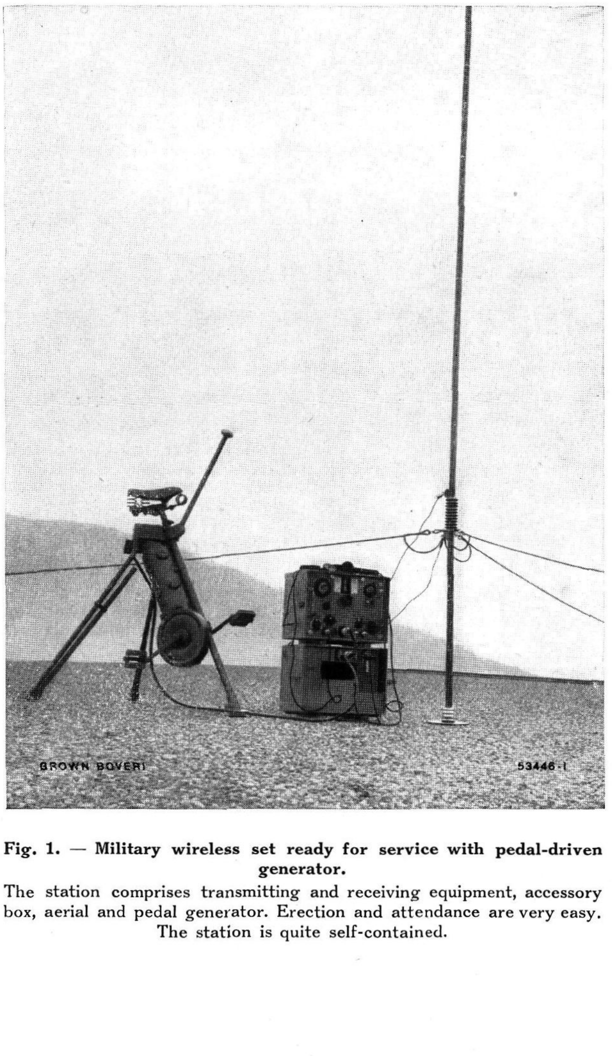

Fig. 1. — Military wireless set ready for service with pedal-driven generator.
The station comprises transmitting and receiving equipment, accessory box, aerial and pedal generator. Erection and attendance are very easy. The station is quite self-contained.

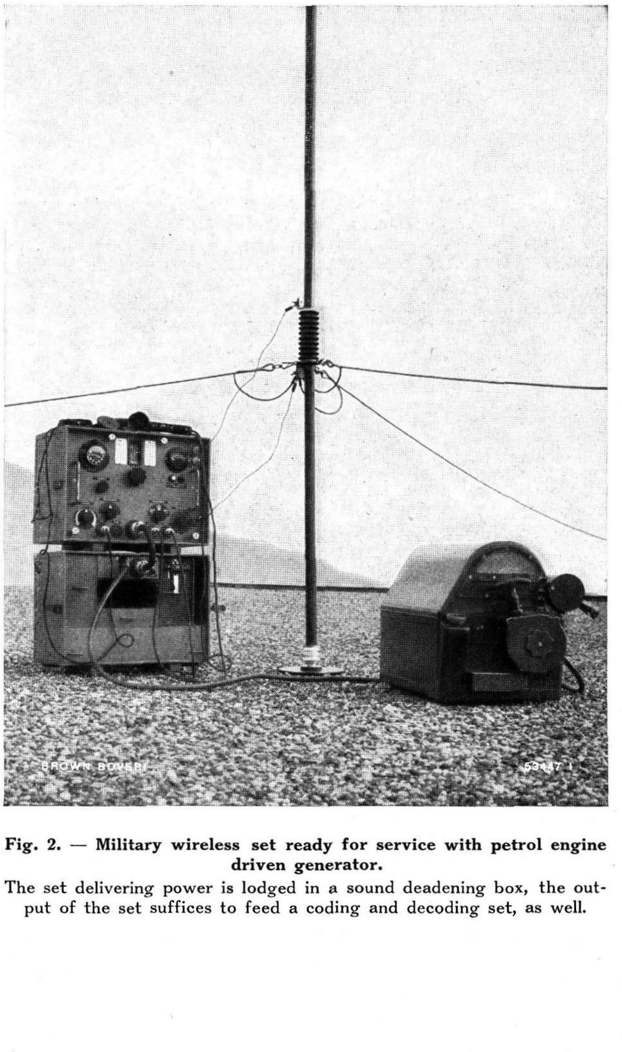

Fig. 2. — Military wireless set ready for service with petrol engine driven generator.
The set delivering power is lodged in a sound deadening box, the output of the set suffices to feed a coding and decoding set, as well.

Brown Boveri have now developed an equipment which, as regards dimensions, weight and output, is in marked progress on apparatus used up till to-day. With a weight of the transmitter-receiver of only 23 kg, our type SET 2/10 station gives a carrier output of 10 W so that, with 100 % modulation, the high-frequency output amounts to 15 W. A considerable change as compared to equipments used up till now is the possibility of regulating the output power. This can be carried out directly by means of a step switch so that it is possible at all times to work with the smallest possible amount of power necessary. By using a cristal microphone, 95 % of syllables and 99 % of sentences can be understood within a range of 300—5000 cycles. In many cases, in the transmission of messages from airmen, this is of great importance because there can be no question of asking for a repetition if the message received has not been understood. The frequency range of this equipment is of the ratio 1 : 3, the longest wave being 180 m and the shortest 20 m. The adjustment of the frequency is carried out on a spiral scale 4 m long, calibrated directly in kilocycles and having an adjustment precision of 0·1—0·2 ‰. It is thus possible to evade a jamming transmitter by a few kilocycles and this even at the highest transmitting frequency.

The receiver is designed for receiving telephone or code messages. The average sensitivity is about 5 μV for 1 mW a — f output. The selectivity and image frequency response satisfies the severest requirements.

Another innovation as compared to apparatus used up till now is that the equipment is absolutely self-contained. For supplying the receiver, there is a storage battery and a converter lodged in the accessory box, it generates the anode voltage, which has to be delivered by dry cells in other apparatus. There is a pedal-driven generator which is the source of current for the transmitter; this generator also serves to charge the storage battery constantly.

We have, further, developed a light petrol engine-generator set to replace the pedal-driven generator for long running periods. It is mounted in a sound-proof casing so that the noise of the engine is not a disturbing factor. The output of this set is such that additional apparatus as, for example, a coding and decoding set can be fed, simultaneously. Figs. 1 and 2 show apparatus Type SET 2/10 ready for service with pedal-driven generator and petrol-engine driven generator respectively.

(MS 816) *Karl Lutz. (Mo.)*

AIRCRAFT WIRELESS.

Decimal index 621.396.933

After a summary description of what aircraft wireless consists of, reference is made to some designs which Brown Boveri have brought out in this field. Mention is made of:— a short range transmitter of 150 W, a short-wave transmitter for meteorological service and special duties 2×500 W and of a remote control system used between the aerodrome and the transmitter building.

THE manner in which the planes on airways succeeded in keeping to their time-tables, before the War, and the long-distance bombing raids carried out over darkened regions, which have been a feature of the War, have aroused widespread interest in the electro-magnetic waves which, penetrating space, allow aircraft crews to ascertain their position and find their way. This brought to light the enormous importance of apparatus which, unknown a few years ago, has been the object of such rapid and successful development and on which, indeed, the safety of aircraft depends on countless occasions.

The astounding progress of aircraft wireless was necessary before blind flying could be undertaken at all. Aircraft wireless, alone, makes possible blind flying through fog and clouds, when the sense of direction of the pilot is based on instruments instead of on eyesight. These instruments have now been so developed that they take over the control of the plane, through automatic devices, eliminating control by the pilot altogether. The following paragraphs are devoted to a closer description of the aircraft wireless which makes such performances possible.

Direction finding employed to fix the position of a plane is of especial importance. It is based on the trigonometrical determination of the position of the plane from two fixed points, which is made possible by the directional properties of certain systems of aerials in emitting or receiving electro-magnetic waves. According to whether this direction finding is carried out from the plane itself to two ground-transmitting stations, or from two fixed direction finding stations to the transmitter on the plane (one station designated as control post communicating the result of the direction finding to the plane), we differentiate between direction finding from the plane and direction finding from the ground. As aerial traffic increases, the earlier direction finding from the ground becomes impossible as it imposes too many duties on the aeronautical stations so that the future belongs to direction finding from the plane. With this system it is also possible to use radio beacons on the ground which are so controlled by time switches that they emit their own particular call signal and then a long dash for tuning the direction-finder.

The entire organisation of direction finding for civilian flying is based on the utilization of medium-length waves. In this wave range, as well, special measures must be taken to eliminate the effects of abnormal polarized waves, due to reflections, so as to prevent possible errors in direction finding. This result is attained to a very considerable extent. With short waves and ultra-short waves, the reflected radiation is preponderant at long distances, thus making these waves improper for direction finding. However, quite recently, this wave range has been utilized successfully, especially for the direction finding of military planes.

If wireless direction finding is of vital importance for flying in bad weather with poor visibility, landing possibilities, under these conditions when the plane has reached its destination, is just as important; it is carried out by means of the blind-landing aids. Quasi optical visibility between aerodrome and plane being available here, ultra-short waves can be utilized for the landing beacons with their auxiliary emitters for the two vertical marker beams. The beacon determines the approach to the aerodrome along which the plane can glide to ground without danger of collision. The second well-known bad-weather landing process, the so-termed z z process, is based on standard ground direction finding. As only one plane can carry out landing manoeuvres over the aerodrome at a time, the aeronautical station can devote all attention to the plane during the time in question.

For communications over air lines and for meteorological service between planes and ground and between ground stations the medium wave-length range is used. However, since some years now, we find the limit range between medium and short waves and the short-wave range itself being introduced for aircraft wireless. For this reason, the last Radio Conference in Cairo, in 1938, foreseeing further developments along these lines, reserved for aircraft wireless certain bands in all the frequency ranges. Most of the aeronautical stations are additionally equipped with teletype machines so that the major part of interstation service can go over wires.

Air traffic, which had developed enormously before the War broke out, made necessary the creation of an organisation to assure the safety of flying. Thus, in Germany, the territory of the Reich was divided up into 12 supervised areas each having one or several auxiliary direction-finding stations. Switzerland was beginning to organize on this principle with two or three areas. When flying into one of these, every plane has to signal its presence to the ground station on a determined calling frequency. In a circle of about 30 km round the aerodrome there is always a short-range zone into which the plane can only enter when the ground wireless station has signalled its assent thereto. This rule is of great value to prevent collisions especially when landing in bad weather.

The equipment of a ground wireless station is considerable on account of the manifold duties it has to perform. A big number of receivers is used for communications with planes which are under way, there is also a number of direction-finding receivers with special aerials for direction finding. A teletype machine plant takes care of a part of the communications with ground wireless stations. Apart from this, a number of transmitters are necessary for the traffic in the supervised area and in the short range, wireless beacons for direction finding and short-wave transmitters for special purposes, for ground service and weather service. Brown Boveri has been most successful in the building of transmitters for aircraft service. One of the first orders booked in the high-frequency field was a short-range transmitter for a Swiss aerodrome. This transmitter (Fig. 1) is mostly operated for i. c. w. telegraphy but can also be used for c. w. telegraphy and telephony. In the first method of operation it gives a carrier wave output of 150 watts and in the two last methods one of about 75 watts to the aerials. The wave range required of 750—1200 m can be smoothly adjusted; within a restricted range

Fig. 1. — Short-range transmitter.
The remote-control cubicles for this transmitter and two other transmitters are seen beside the short-range transmitter.

of 850—950 m in which the working frequences usually employed are found (322, 327, 336 and 340 kC), four fixed frequencies can be tuned to so that switching over to any one of these frequencies can be carried out instantaneously. All the adjusting knobs are locked and, thus, adjustments carried out by unauthorized persons

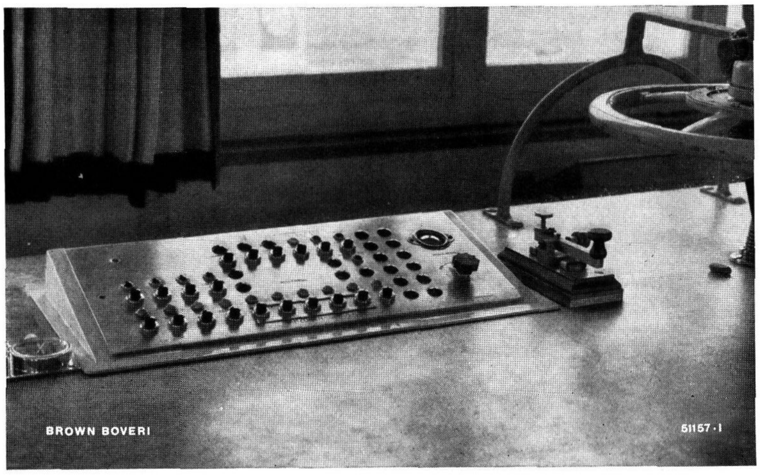

Fig. 2. — **Control board for the remote-control of the short-range transmitter belonging to a ground direction-finding station.**
The small control desk built into the direction-finding table allows of controlling the short-range transmitter placed 10 km away.

are impossible. The transmitter cubicle contains the two-stage high-frequency generator and a 10 watt modulator for operating in A_2 and A_3; further it holds all the rectifiers for the anode and grid voltages. The aerial transformer is lodged in a separate casing just beside the aerial incoming lead; it is automatically adjusted by relay when a wave change is carried out. Measurements on the aerials show that the aerial characteristic varies considerably under hoar-frost formation, which occurs frequently. In order to take this into account as well, the transformer has the requisite tuning means. This short-range transmitter was put to work in the summer of 1939 and the first measurements made showed how excellent it was. The constancy of frequency, higher harmonics in the carrier wave, frequency response and distortion factor, were all within the values allowable and guaranteed. A range of up to 250 km was measured for the output of 150 watts. Especial mention should be made of the great reliability of the apparatus; no trouble has arisen during the time it has been in use, which exceeds two years, now.

Aerials belonging to aircraft transmitting stations are undesirable in proximity to aerodromes as they are obstacles which may be dangerous to planes especially during blind landing in bad weather. On the aerodrome already mentioned, the occasion of putting in the aerodrome transmitter was utilized to connect the transmitting post to the aerodrome by a Brown Boveri remote control. The operation of the transmitter used to be carried out by the personal of the wireless station through orders imparted by telephone, and this often meant loss of time. Now, these operations are carried out directly by the telegraph operator in control of traffic. This has lightened the work of the operating personel, which is of great importance in view of the amount of work to be done which increases as the station grows. The plant comprises the remote control of three transmitters:— the short-range transmitter and the already existing supervised-area transmitter and the meteorological-service transmitter. The control of the short-range transmitter and of the supervised-area transmitter can be carried out, as desired, from two direction-finding posts on the aerodrome while that of the meteorological-service transmitter is from a third building on the aerodrome. For the situation thus created which is not simplified by there being several control posts, the Brown Boveri single impulse system (EI system) has proved most suitable. Keying, talking and remote control of a transmitter are

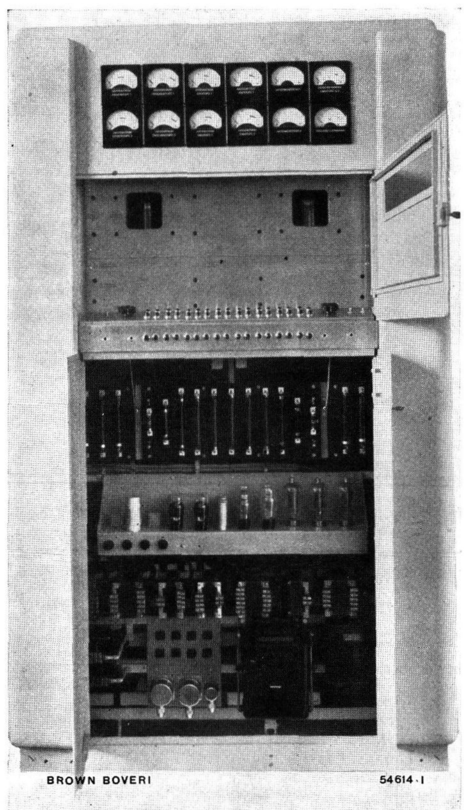

Fig. 3. — **Short-wave transmitter for aircraft supervision service 500 W/1000 W.**
The short-wave transmitter is used for communications with other aerodromes and for the meteorological service. Despite a very compact design all separate parts are easy to supervise and easy of access.

all through one and the same conductor, keying with a. c. and control with d. c. The arrangement with 25 possible double signals, each consisting of an order impulse and back signal is carried out by a step selector, the synchronous advance of which is carried out alternatively from the control post and the remote post so that, practically, a faulty switching operation is impossible. A rotation of the selective switch over the 25 double positions takes about 10 seconds. This time is necessary for the carrying out of the order corresponding to the last switch position. The selective arrangement on the switch according to the importance of the order prevents any undesirable retardation in service. Fig. 1 shows parts of the remote control for the transmitter mentioned. Fig. 2 shows one of the control boards of the direction-finding station, which are very well designed and easy to supervise. After the first troubles on the lines of the remote control, which arose at the first setting to work, had been revealed by measurements and eliminated, operations were taken up and carried out for two years faultlessly and without the slightest hindrance.

A short-wave transmitter for the same aerodrome should also be mentioned here, although it has not been put in yet. This transmitter is chiefly intended for the meteorological and ground services but should also fulfil other duties. The wave range is 20—110 m which is attained by two high-frequency transmitters lodged in a single cubicle. The first of these is for a range of 20—45 m and the second for a range of 30—110 m. Each transmitter can generate a maximum high-frequency output of 500 watts in the common range. With control of both power amplifiers from the oscillator of one transmitter both together can generate a maximum of 1 kW. In each of the ranges, two frequencies can be tuned to and are immediately ready for service by switching over. Fig. 3 shows the transmitter complete. This external design has been standardized and used in other plants as well.

The requirement that the transmitter should be able to be displaced along with the remote control, which latter must be effective when the transmitter is used for special purposes over distances up to about 100 km, makes it impossible to use the EI system with which the plant is already equipped and makes necessary putting in the impulse-combination system (Brown Boveri IK system) with which a.-c. impulses exclusively are transmitted. The 11 signals necessary for the control of the transmitter can be amplified and transmitted further by standard telephone-line amplifiers, so that the distances over which the signals are transmitted can be increased as much as desired.

(MS 817) *Dr. W. Lindecker. (Mo.)*

FREQUENCY MODULATION.

Decimal index 621.396.619.018.4

Frequency-modulation characteristics and advantages are discussed and compared to amplitude modulation.

This system, in full development in the United States, has had our attention for a considerable time. Researches made as well as experience acquired on a frequency modulated installation have fully confirmed the favourable properties of this system.

TRANSMISSION of a-f signals can be produced, as is well known, in the form of modulated h-f oscillations. For these oscillations, having an amplitude a and a pulsation ω, the following equation is generally verified:

$$e = a \cdot \sin \varphi(t) = a \cdot \sin \int \omega \, dt \qquad (1)$$

In amplitude modulation (AM), the pulsation ω remains a constant, while amplitude a, corresponding to an instantaneous value of the a-f signal, deviates from the average a_o by a variable quantity a_n. The signal may be composed of an a-c voltage, having a pulsation $\omega_N = 2\pi f_N$ (with a capital letter index). Equation (1) therefore becomes:

$$\begin{aligned} a &= a_o + a_n = a_o (1 + m_a \cdot \sin \omega_N t); \\ \omega &= \omega_o = \text{constant} \end{aligned} \qquad (2)$$

The rate of modulation m_a can attain the value of 1, according to the signal amplitude.

In *frequency modulation* (FM), the amplitude a remains a constant, while pulsation ω, corresponding to the signal to be transmitted, deviates from the average value ω_o:

$$\begin{aligned} \omega &= \omega_o + \omega_n = \omega_o (1 + m_f \cdot \sin \omega_N t); \\ a &= a_o = \text{constant} \end{aligned} \qquad (3)$$

The shift $\omega_n = 2\pi f_n$ (characterized by the non-capital letter index) between the instantaneous value $\omega = 2\pi f$ and an average one of $\omega_o = 2\pi f_o$ of the pulsation, has the maximum value of $\omega_h = 2\pi f_h = m_f \cdot \omega_o = 2\pi m_f \cdot f_o$. The maximum frequency deviation $f_h = m_f \cdot f_o$ is usually much smaller than the average frequency f_o; which means that in FM, the shift ratio m_f is always small as compared to 1. A comparison of both modulation systems, and notwithstanding the apparent analogy between the equations (2) and (3), shows important differences in the nature of the oscillations, perturbations and distorsions which are caused, as well as in the transmitting devices.

Frequency modulated oscillations consist of a carrier frequency f_o and of two side-bands with a shift up and down amounting to the signal frequency f_N. In the case of FM, a decomposition into a Fourier series shows a frequency spectrum of a large number of components grouped around an average frequency f_o and deviating one from another by the value of the signal frequency f_N. The comparison shows that the FM transmitted band width is much larger than the one needed in AM.

I. DISTORSIONS AND PERTURBATIONS.

Non-linear elements of circuits (valves with curved characteristics, etc.) always produce non-linear distorsion in the transmitted signal, generating higher harmonics, frequency combinations, etc. Transmission of sine-wave oscillation in a circuit of non-linear characteristic $a_z = f(a)$ leads not only to a fundamental frequency a_1, with a pulsation ω_N, but also to numerous perturbing components a_μ, having a pulsation $\mu \cdot \omega_N$

$$a_1 = A_1 \cdot \sin(\omega_N \cdot t) \quad (4)$$

$$a_\mu = A_\mu \cdot \sin(\mu \cdot \omega_N \cdot t) \quad (5)$$

The importance of the perturbing components is given by the signal-to-noise ratio c_μ

$$c_\mu = \frac{A_\mu}{A_1} \quad (6)$$

The suppression of non-linear distorsions presents many difficulties in AM.

In FM, the instantaneous pulsation alone determines the transmitted signals. Amplitude variations due to non-linear characteristics can be suppressed at the receiver by means of amplitude limitors. The frequencies not being modified, there will be no audible signal distorsion.

Oscillating transmission circuits cause *phase distorsion* of the modulated oscillation, the phase characteristic of these circuits being a function of the frequency $\varphi_z = f(\omega)$. While these distorsions are only of little importance in AM, supplementary frequency variations due to additional phase differences may provoke a non-linear signal distorsion in FM.

In FM of h-f oscillation, periodical variations of the instantaneous pulsation ω_N take place, according to (3), in rhythm with the a-f signal $f_N = \frac{\omega_N}{2\pi}$. These frequency variations provoke, at the output of the phase distorted circuit, additional periodical variations φ_z which are composed of numerous components:

$$\varphi_1 = \Phi_1 \cdot \sin(\omega_N t) \quad (7)$$

$$\varphi_\mu = \Phi_\mu \cdot \sin(\mu \cdot \omega_N t) \quad (8)$$

When the phase distorsion characteristic $\varphi_z = f(\omega)$ has the same curve in the range considered as the non-linear transmission characteristic $a_z = f(a)$, the ratio of φ_μ components is equal to the ratio of perturbing a_μ components of one of the a_z oscillations distorted through non-linear transmission:

$$\frac{\Phi_\mu}{\Phi_1} = \frac{A_\mu}{A_1} = c_\mu \quad (9)$$

Supplementary phase shifts call forth corresponding perturbing components of the instantaneous pulsation:

$$\omega_z = \frac{d\varphi_z}{dt} \quad (10)$$

$$\omega_1 = \frac{d\varphi_1}{dt} = \Phi_1 \cdot \omega_N \cdot \cos(\omega_N t) \quad (11)$$

$$\omega_\mu = \frac{d\varphi_\mu}{dt} = \Phi_\mu \cdot \mu \cdot \omega_N \cdot \cos(\mu \cdot \omega_N t) \quad (12)$$

The a-f signal obtained by detection is proportional to the instantaneous frequency deviation $\omega_N + \omega_z$ of the h-f oscillation. It thus contains perturbing components which are in the same amplitude ratio to the effective component as the maxima values $\Omega_\mu = \Phi_\mu \cdot \mu \cdot \omega_N$ and $\omega_h = 2\pi f_h$ of the corresponding periodical frequency variations ω_μ and ω_n. The perturbing factor k_μ, characterizing the a-f distorsion spectrum is given by:

$$k_\mu = \frac{\Omega_\mu}{\omega_h} = \frac{\Phi_\mu \cdot \mu \cdot \omega_N}{\omega_h} L - + c_\mu \cdot \frac{\Phi_1}{\omega_h} \cdot \mu \cdot \omega_N \quad (13)$$

As the quotient of the maximum phase shift Φ_1 by the maximum frequency variation ω_h provoking this variation, coincides with the transmission time T_o, we obtain

$$\underline{k_\mu = c_\mu \cdot T_o \cdot \mu \cdot \omega_N} \quad (14)$$

The transmission time is very short, owing to the large band width of all tuned circuits, so that the product $T_o \cdot \mu \cdot \omega_N$ remains smaller than 1, even if the transmission channel comprises several filter circuits.

This is the reason why non-linear distorsions of a signal in FM can easily be kept very small. This modulation method is, therefore, recommended in all circumstances needing a highly linear transmission, for instance in multiple transmission.

Contrary to AM, FM renders possible a high fidelity transmission of d-c values, such for example as continuous components of television signals which determine the average luminosity of the image. As, owing to the factor $\mu \cdot \omega_N$ of k_μ, there is no distorsion component for frequencies approaching O, FM seems to be most appropriate for the transmission of measures, and we are developping a remote measure transmitting system, where the measured values are characterized by frequency variations of a carrier.

Perturbing oscillations, valve-noise, etc. are most important factors; they may provoke perturbations which will considerably diminish the use of AM. A study of the influence of these perturbations on FM may be made with the help of Fig. 1. Vector $\mathfrak{a}_o$, rotating through the increasing angle $\varphi(t)$, represents the effective oscillation

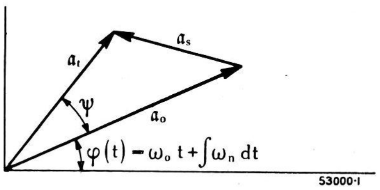

Fig. 1. — Vector-diagram of the perturbed received oscillation.

$\mathfrak{a}_o$. Pure received oscillation.
$\mathfrak{a}_s$. Perturbing oscillation.
$\mathfrak{a}_t$. Perturbed received oscillation.
ψ. Resulting phase-shift.

The perturbed oscillation is phase-shifted, at an angle ψ, to the pure oscillation.

(1) received. Vector $\mathfrak{a}_s$ is a perturbing oscillation having an amplitude a_s. Amplitude a_t of the oscillation received can always be brought to a constant value by means of amplitude limitation. There exists, though, a phase shift $\psi(t)$ which means that a distorted oscillation is received.

$$e = a_o \cdot \sin [\varphi(t) + \psi(t)] \tag{15}$$

The maximum value of the phase shift Ψ can be determined geometrically

$$\Psi = \text{arc sin} \left(\frac{a_s}{a_o} \right) \tag{16}$$

In case of small perturbing amplitudes, Ψ is proportional to the perturbing rate of AM:

$$\Psi \approx \frac{a_s}{a_o} = p \tag{17}$$

If the phase-shift ψ has a sine-variation between extreme values $\pm \Psi$, with a pulsation ω_s, there will be a corresponding frequency variation ω_z, which is periodical too:

$$\psi = \Psi \cdot \sin(\omega_s t) \tag{18}$$

$$\omega_z = \frac{d\psi}{dt} = \Psi \cdot \omega_s \cdot \cos(\omega_s t) \tag{19}$$

The perturbing component of an a-f signal, due to ω_z, is in the same ratio to the maximum effective amplitude as the corresponding maxima pulsation variations $\Omega_z = \Psi \cdot \omega_s$ and $\omega_h = 2\pi f_h$.

The perturbing rate will then be defined as follows:

$$\underline{q_s = \frac{\Omega_z}{\omega_h} = \frac{\Psi \cdot \omega_s}{\omega_h} = \frac{a_s}{a_o} \cdot \frac{\omega_s}{\omega_h} = p \cdot \frac{f_s}{f_h}} \tag{20}$$

The audible perturbation thus grows with increasing frequency and is at its maximum when its frequency attains the highest signal frequency f_H which can still be transmitted across the a-f filter:

$$q_H = p \cdot \frac{f_H}{f_h} \tag{21}$$

Even with such unfavourable conditions, the amelioration would still be noteworthy with regard to the AM perturbing rate; it corresponds to the ratio of the extreme audible frequency f_H to the frequency

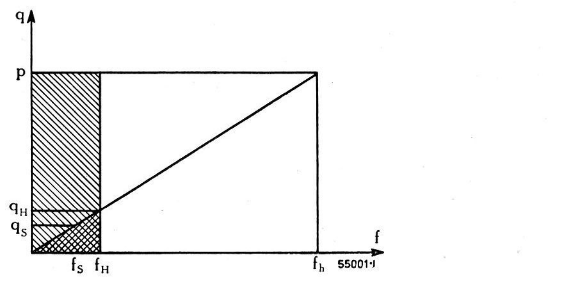

Fig. 2. — Perturbing factors in AM and FM.

f_h. Frequency-shift.
f_H. Maximum signal frequency.
f_S. Audible perturbing frequency.
$p = \frac{a_s}{a_o}$. Perturbing factor in AM.
$q_S = p \cdot \frac{f_S}{f_h}$. Perturbing factor in FM.
$q_H = p \cdot \frac{f_H}{f_h}$. Maximum perturbing factor in FM.

In case of an important frequency-shift f_h, FM perturbing factors q_S are small as compared to AM perturbing factors p. The ratio of average perturbing factors is that of the two shaded surfaces.

shift f_h. The perturbing rate is 0 when the perturbing frequency f_S disappears, so that FM of continuous values (remote measures, for instance) will be particularly appropriate and insensitive to perturbations.

It has been admitted in any case in these considerations that the amplitude a_s of the perturbing voltage is smaller than the signal amplitude a_0. It is, indeed, only under such circumstances, that the perturbations during reception will be apparent as determined and relatively small variations ψ only, between the limits of Ψ, according to (15) and (16). As soon as p becomes bigger than 1, audible perturbations increase rapidly and cover the signal.

Fig. 2 is a graphical representation of the equation (20). The average attenuation Q_i of the periodical audible perturbation, gained by means of FM, corresponds to the ratio of the shaded surfaces:

$$Q_i = \frac{p}{q_m} = \frac{2 f_h}{f_H} \tag{22}$$

A similar result is obtained with static perturbations due, for instance, to the valve noise. The peak of the perturbation is in this case equal to the sum of the squares of the amplitudes of all the perturbing oscillations, in other words it is the integral of the ordinate squares of both shaded surfaces. The attenuation Q_r of the perturbing signal thus corresponds to the square root of the power output ratio:

$$Q_r = \sqrt{3} \cdot \frac{f_h}{f_H} \tag{23}$$

II. PRACTICAL CONDITIONS.

The equations (22) and (23) show that the amelioration of the receiving conditions will increase when the frequency shift f_h increases. This shift is limited however by the transmission band width. The perturbing rate p also increases if the receiving band grows larger; nevertheless, this rate must be smaller than 1. The frequency shift has been chosen, after many tests and thanks to the experience acquired, three to five times as high as the maximum signal frequency. For speed transmission at maximum 3000 cycles, the frequency shift will be of 10,000 to 15,000 cycles, whereas for music transmission, a shift of 50 to 75 cycles would be appropriate.

The factor Q characterizing the diminution, due to FM, of the perturbing rate, is about equal to 10, which means that the level of the audible perturbation is lessened by roughly 2·5 Neper for the same reception amplitude. As the ratio p between the perturbing and the signal amplitudes may be increased by the same quantity, the transmission can thus reach a larger area.

These interesting results have all been confirmed by numerous tests under the most varied local and reception conditions.

Referring to equations (14) and (20), the amplitude of audible perturbations, due to phase distorsions and atmospherics, will increase with increasing frequency. As to the effective signal components of higher frequencies, their amplitude is normally relatively small. It is, therefore, recommended to increase the higher frequency signal amplitude before the modulation process — in case of transmission, and to diminish it correspondingly, after demodulation, in case of reception. The frequency shift is thus but slightly increased, but such an attenuation reduces considerably audible perturbations at higher frequencies, which are particularly disagreable.

An important advantage of FM consists in the fact that when two h-f modulated oscillations are simultaneously received, the lowest of the two is suppressed by the higher one. Oscillations of smaller amplitude, which can indeed be considered as perturbing oscillations, will produce, according to (15) and (17), but small variations $\psi \leq p$ of the highest oscillation phase; thus, the corresponding frequency error produces but slight audible perturbations. Because of this, the interference zone between two transmitters operating on the same frequency is much smaller with FM than with AM.

This has also been confirmed by our tests made with FM and AM transmitters. During a simultaneous transmission with FM and AM, the reception was impossible with the AM receiver. As to the FM receiver, only the strongest emission could be heard. With a receiving voltage in AM of 12·7 μV and 14·0 μV (10 %) stronger) in FM, the received signal in the FM receiver was perfectly clear and there was but little whistling. Diminishing the FM reception voltage to 11·5 μV, the AM transmitter became clearly heard in the same receiver.

With chain-broadcasting, that is with the same program being broadcasted from several stations, no audible superposed perturbations will be heard if care is taken to vary slightly the different frequencies of the stations. In this case, there is no need to synchronize the transmitted oscillations, as is the case in AM. Thus, with FM broadcasting, it is possible to have a certain number of smaller stations, installed for instance in the neighbourhood of towns, instead of a smaller number of powerful stations having a greater power. The total cost and power of broadcasting stations may be thus greatly reduced.

Another advantage of FM is that the amplitude variations due to fading phenomena may be completely balanced by means of simple amplitude-limitation, so that during instantaneous fading no variation will be noticeable, while over-modulation in AM leads notoriously to a disagreable distorsion. Short excesses of frequency shifting are usually of no importance in FM. It is, therefore, unnecessary to survey very strictly the transmitted signal-level.

Because of the large band width of FM signals, corresponding to about two and a half times the frequency shift, it is still impossible to use FM in the medium wave-band broadcasting. This band width is no more important, however, in case of h-f ultra-short waves and FM will, therefore, find its application particularly with wave lengths of a few meters. Frequencies of somewhat longer wave lengths can also be used.

In case of line-transmitted frequency-modulated oscillations, a limited noise-influence will contribute to a smaller cross-talk. Even a very poor decoupling of the transmission channels will show an appreciable cross-talk attenuation of any frequency-modulated signals.

III. TRANSMITTER AND RECEIVER APPARATUS.

The amplitude of a given carrier oscillation is usually controlled in AM in accordance with the transmitted signal. A method of this kind would not be appropriate in FM, as the frequency of a given carrier cannot be modulated by simple means. This is the reason why tuning of the FM master-oscillator will be usually modified according to the signal. The tuning may be accomplished by way of a circuit comprising reactively coupled valves. It is also possible to influence the inductance of the oscillating coils, by varying the magnetic state of an iron core. It is, finally, possible to obtain a tuning control by means of dry bias rectifiers having a relatively small capacity. Numerous tests have shown us the possibility of varying these capacities largely by way of bias variation.

A linear relation between frequency variation and the control voltage is very important. In the case of reactance valve-control it is, therefore, recommended to choose a valve having the most linear characteristic possible of the grid bias. Although smaller frequency shifts are of less importance in FM because of the large frequency spectrum band width, as constant a medium frequency as is possible is naturally desired. Superposing a h-f oscillation of constant frequency, a control voltage may be, for instance, obtained, corresponding to an instantaneous average frequency and acting so as to diminish any tuning errors on the oscillating generator. Even through careful compensation of temperature and voltage variations of a FM generator, a frequency constancy of roughly 0·025 to 0·1 ‰ can be obtained without using any such control devices.

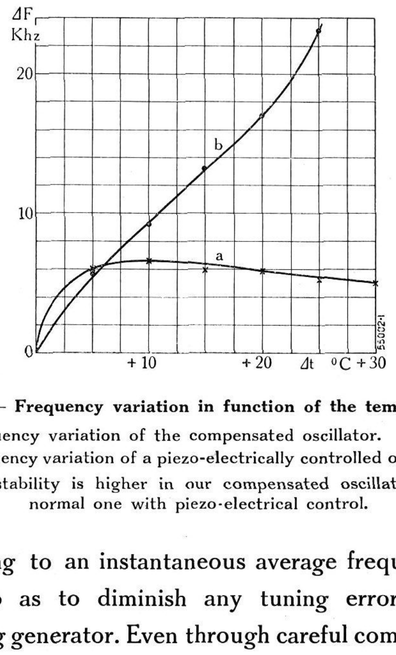

Fig. 3. — Frequency variation in function of the temperature.

a. Frequency variation of the compensated oscillator.

b. Frequency variation of a piezo-electrically controlled oscillator.

Frequency stability is higher in our compensated oscillator than in a normal one with piezo-electrical control.

A direct tuning control with frequencies of over 20 Mc being somewhat difficult, the controlled oscillator is usually driven by lower frequencies and the higher transmitting frequency is obtained by way of frequency multiplication.

The average oscillator frequency of one of our stations is of about 10 Mc. This frequency is doubled in the final stage after having been trebled in the intermediate one, so that an average transmitting frequency of roughly 60 Mc is thus obtained. The mechanical, thermal and electrical stability of this automobile station has proved to be excellent: no noticeable modulation is brought about due to shocks during conveyance. An automatic frequency stabilizing device could not be used because of the necessity of having a low weight, but a temperature compensating device has been provided for, so that any frequency variations due to temperature are kept bellow 0·1 ‰. After reaching the normal service temperature, any variation of the latter is, according to Fig. 3, smaller than in the case of a normal valve oscillator with piezo-electric control.

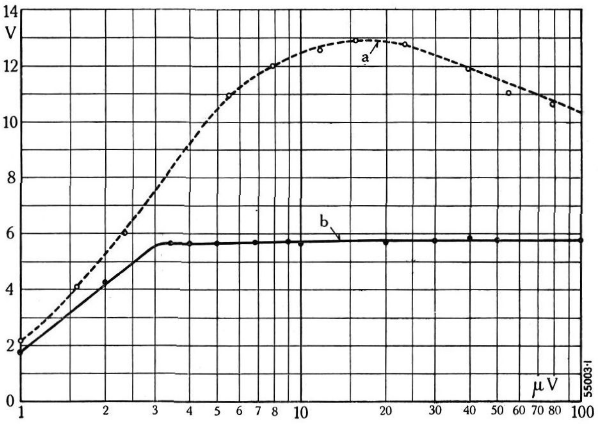

Fig. 4. — Limitor characteristic curves.

(Amplitude of the limited voltage in function of the strength of the receiving field.)

a. Measured curve of a normal limitor.
b. Measured curve of our new limitor.

Contrary to usual limitor-circuits, a practically constant voltage-amplitude is obtainable over a wide range by means of our limitor.

A fairly good electric stability would be obtained by means of specially designed circuits: a 25 % decrease of the plate voltage results in about a 0·02 ‰ frequency variation only.

The frequency shift of this apparatus has been fixed to 15 Kc. The oscillating frequency variations are thus of ± 2·5 Kc. Distorsion factors have been measured for the total output of the signal input in the transmitter up to the receiver detection; they are lower than 1 % even in over-modulating with a frequency shift of 20 Kc.

At the detector stage, frequency variations of the received oscillations are transformed into corresponding amplitude variations which are then detected in the usual way. According to the usual detection method, used generally to-day, the a-f voltage is obtained by forming the modulation-product of the input and output voltages of a frequency phase-shifted network.

The amplitude limitation of the receiver oscillations is most important for good audition; the amplitude has to be brought to a constant value a_o, independently of the superposed perturbing oscillations. Because of the unsatisfactory action of some known limitor-circuits, we have designed a quite new limitor-system giving a practically constant output amplitude even with considerable input-voltage variations. According to Fig. 4, the measured amplitude curve is practically linear on a large scale, whereas for other known limitors, it is wholly non-linear.

FM transmitters are characterized by the high efficiency of their full output-operating stages, all non-linear distorsion being practically of no influence. Compared to similar AM transmitters, and according to particular circumstances and use, a gain of 20 to 40 % can be obtained in weight, volume and power-output. This gain is still more important when it is remembered that a less powerful FM transmitter will cover the same area as an amplitude modulated one.

On the other hand, FM receivers are rather more bulky; because of the band width and of the higher frequencies, more amplifier-stages must be available, and, on the other hand, this more complicated design is also due to additional means of amplitude-limitation and demodulation.

The transfer of cost from the transmitter to the receiver represents an advantage with the application of FM to radiophony or to military use. But this is naturally undesirable in broadcasting, where a small quantity of transmitters operate for the benefit of a great many receivers. FM would not seem to be suitable in all cases where a receiver of low cost is preferred at a possible sacrifice of reception-quality. If, though, interest is attached in obtaining a high-fidelity reception, which is either impossible or only obtainable at high cost in AM, there would seem to be a great future for FM.

We had the opportunity of studying fully the FM-method in designing some time ago one of the important european FM-operating stations. The experience thus acquired, as well as the good results achieved, encourage us to apply this modulation method to other projects.

G. Guanella and J. Schwartz. (E. H.)

THEORY OF A COUPLED CIRCUIT SYSTEM CONSISTING OF TWO OSCILLATORY CIRCUITS CONNECTED BY A LINK LINE.

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Circuit systems consisting of two oscillatory circuits connected by a link line occur quite frequently, for instance, in transmitters and amplifiers. The effect on the behaviour of such systems in service, of different loads and of different values of the various circuit elements, is here investigated.

I. INTRODUCTION.

COUPLED systems consisting of two oscillatory circuits connected by a more or less long link line are frequently encountered in transmitters, either because two oscillatory circuits, which may be required for various reasons, have to be coupled together, or because high frequency power has to be transmitted over a certain distance. The latter case practically always occurs where the transmitter is connected to aerial. At the output side of the transmitter there is the tank circuit, whilst the aerial itself also constitutes an oscillatory circuit. The two are connected by a link line. Inside the transmitter it is not always possible to avoid an arrangement with an anode circuit and a grid circuit between consecutive stages, especially in the case of short wave transmitters, so that the same coupled system occurs again here, and it can accordingly to some extent be considered as a fundamental component element.

Although basically quite simple, the mutual influences are numerous and varied, and hence their effects cannot be visualized without closer investigation. It is true that the relations may be summarised in a few formulae, but these are of little use to the designer or to the operating engineer if they are not accompanied by an analysis of the mutual dependencies and influences, especially in regard to those magnitudes which are altered or which are liable to variation in practical service. Only a consideration of the conditions in practical service shows how to dispose of the excessive degrees of freedom in choosing the arrangement so as to arrive immediately at the right solution. It is then found that the apparent indeterminancy is entirely eliminated by the requirements of practical operation, so that generally only one solution is obtained and free assumptions are not possible.

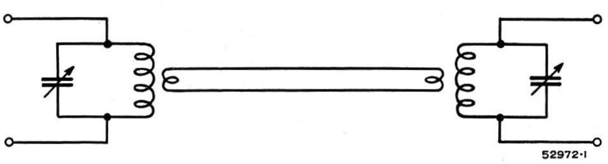

Fig. 1. — Coupled system comprising two oscillatory circuits connected by a link line.

The following study is devoted to an analysis in this direction. The diagram Fig. 1 shows the fundamental arrangement of the circuit considered.

II. INPUT SIDE.

(a) *Symbols of input side:*

L_1 Oscillatory circuit inductance
L_2 Coupling inductance
L_2' Inductance in series with the coupling coil
M Mututal inductance between L_1 and L_2
C_1 Oscillatory circuit capacity
C_2 Capacity of coupling circuit
$\mathfrak{Z}_\ell$ (Vector) impedance of the loaded branch of the oscillatory circuit induction
Z_ℓ Absolute value of $\mathfrak{Z}_\ell$
Z_q Z_ℓ referred to secondary side
R_p Resulting parallel resistance of $\mathfrak{Z}_\ell$
R_s Resulting series resistance of $\mathfrak{Z}_\ell$
R_q R_p referred to secondary side
$\mathfrak{R}_2$ Load impedance of coupling system
R_2 Load resistance of coupling system
R_{20} Optimum load resistance of coupling circuit
X_p Resulting parallel reactance of coupling circuit
X_s Resulting series reactance of coupling circuit
X_q X_p referred to secondary side
$X_{2\lambda}$ Total leakage inductance referred to coupling circuit
X_{2s} Additional series reactance in the coupling circuit
$\mathfrak{Y}_\ell$ Admittance due to oscillatory circuit inductance
G Conductance due to oscillatory circuit inductance
B Susceptance due to oscillatory circuit inductance
k Coupling factor
k_s Coupling factor for a series load circuit
k_p Coupling factor for a parallel load circuit
k_o Minimum coupling factor
Q Figure of merit of oscillatory circuit
ω Angular velocity
$\mathfrak{U}_1$ U_1 Vector and r. m. s. value of oscillatory circuit voltage
$\mathfrak{U}_2$ U_2 Vector and r. m. s. value of the voltage at the coupling coil
$\mathfrak{U}_c$ U_c Vector and r. m. s. value of the voltage across the condenser in the coupling circuit
$\mathfrak{J}_1$ I_1 Vector and r. m. s. value of the current in the inductance of the oscillatory circuit
$\mathfrak{J}_2$ I_2 Vector and r. m. s. value of the current in the coupling coil
$\mathfrak{J}_c$ I_c Vector and r. m. s. value of the current in the condenser of the coupling circuit.

(b) *Load consisting of a pure ohmic resistance.*

Under properly adjusted service conditions the feeder line is terminated by a pure ohmic resistance equal to the surge resistance of the line, so that the impedance on the input side is also a pure ohmic resistance. It is, therefore, particularly interesting to investigate the mutual relations with a pure ohmic load according to Fig. 2.

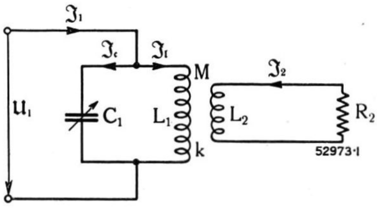

Fig. 2. — Coupling coil loaded with a resistance.

The mutual inductance M and the coupling factor k are related to the two inductances L_1 L_2 by the general expression

$$M = k\sqrt{L_1 L_2}$$

The starting point of the investigation is the impedance

$$\mathfrak{Z}_l = \frac{\mathfrak{U}_1}{\mathfrak{J}_l}$$

of the loaded inductive branch of the circuit. This is determined by the two equations

$$\mathfrak{U}_1 = \mathfrak{J}_l\, j\,\omega\, L_1 + \mathfrak{J}_2\, j\,\omega\, M$$

$$\mathfrak{U}_2 = \mathfrak{J}_2\, j\,\omega\, L_2 + \mathfrak{J}_l\, j\,\omega\, M + \mathfrak{J}_2 R_2 = O$$

Solving the second equation for $\mathfrak{J}_2$ and substituting in the first one gives the result

$$\mathfrak{Z}_l = \frac{j\,\omega L_1 R_2 - \omega^2 L_1 L_2 (1-k^2)}{R_2 + j\,\omega L_2} \tag{1}$$

or, rationalized

$$\mathfrak{Z}_l = \frac{\omega_2 L_1 L_2 R_2 k^2 + j\,\omega L_1 [R_2^2 + \omega^2 L_2^2 + (1-k^2)]}{R_2^2 + (\omega L_2)^2}$$

Considered as a series circuit, the equivalent resistance is

$$R_s = R_2 \frac{\omega^2 L_1 L_2 k^2}{R_2^2 + (\omega L_2)^2} \tag{2}$$

and the inductance to be compensated by a series connected capacity is

$$X_s = \omega L_1 \frac{R_2^2 + (\omega L_2)^2 (1-k^2)}{R_2^2 + (\omega L_2)^2} = \frac{1}{\omega C_1}$$

$$\therefore C_1 = \frac{1}{\omega^2 L_1} \frac{R_2^2 + (\omega L_2)^2}{R_2^2 + (\omega L_2)^2 (1-k^2)} \tag{3}$$

As long as R_2 is large compared with ωL_2, the value of C_1 is that corresponding to the no-load tuning of the circuit. As R_2 decreases to 0, C_1 increases (correction of the tuning) by the factor $\frac{1}{1-k^2}$.

Since according to Fig. 2 C_1 is in parallel with L_1, it is necessary for the purpose of analysis to resolve $\mathfrak{Z}_l$ into parallel components.

$$\mathfrak{Y}_l = \frac{\omega L_2 R_2 k^2 - j[R_2^2 + (\omega L_2)^2 (1-k^2)]}{\omega L_1 [(\omega L_2)^2 (1-k^2)^2 + R_2^2]} = G + jB$$

where $R_p = \frac{1}{G}$ is the parallel resistance.

The parallel inductance X_p compensated by tuning with C_1 is

$$X_p = \frac{1}{\omega C_1} \quad \text{or } B = \omega C_1$$

$$R_p = \frac{L_1}{L_2 R_2 k^2} [(\omega L_2)^2 (1-k^2)^2 + R_2^2] \tag{4}$$

$$C_1 = \frac{1}{\omega^2 L_1} \frac{R_2^2 + \omega^2 L_2^2 (1-k^2)}{R_2^2 + \omega^2 L_2^2 (1-k^2)^2} \tag{5}$$

R_p varies with R_2 as shown by the curves Fig. 3 (k being the variable parameter).

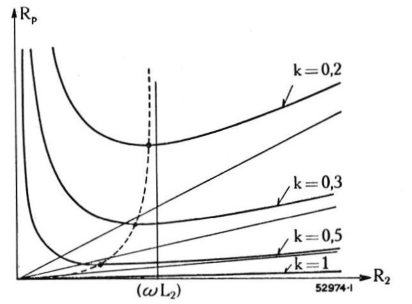

Fig. 3. — Parallel loading of the circuit as function of the load resistance and of the coupling factor.

To every degree of coupling, there corresponds a definite line resistance R_{20}, which makes the load a maximum, i. e. which makes R_p a minimum.

Calculation then gives

$$\underline{R_{20} = \omega L_2 (1-k^2)} \tag{6}$$

In practice, k hardly ever exceeds 0·5 and generally remains well below this value, so that R_{20} may be taken as being practically equal to ωL_2 and may be considered as constant throughout the variable range of coupling.

With $R_{20} = \omega L_2$, R_p only depends on L_1 and k.

$$R_p = \omega L_1 \frac{1 + (1-k^2)^2}{k^2}$$

The attainable minimum value of R_p is then for $k = 1$

$$R_{p\,\min} = \omega L_1$$

With k less than 1, $R_{p_{\min}}$ increases correspondingly. With $R_{20} = \omega L_2\ (1-k^2)$, ($R_2$ being continuously matched to the degree of coupling) R_p depends on L_1 and k as follows:

$$R_p = 2\omega L_1 \frac{1-k^2}{k^2} \tag{7}$$

With increasing coupling R_p may be reduced down to zero.

Apart from the disturbing effect on the tuning (see below) R_p is transmitted to the primary side with a transformation ratio depending not only on $\frac{L_1}{L_2}$ and k, but also on R_2 itself. Then

$$\frac{R_p}{R_2} = \frac{L_1}{L_2 k^2} \cdot \left[1 + \left(\frac{\omega L_2}{R_2}\right)^2 (1-k^2)^2\right] \tag{8}$$

$\left(\text{Instead of } \frac{L_1}{L_2 k^2} \text{ there may be put } \frac{L_1^2}{M^2}\right)$.

With decreasing R_2 the transformation ratio increases from its ideal value for $R = \infty$ which is $\frac{L_1}{L k^2}$ until with $R_2 = R_{20}$ the ratio $\frac{R_p}{R_2}$ has doubled.

Basing on the above calculation and using vector representation, the relationships can be expressed by the vector diagram Fig. 4. R_q is the primary parallel resistance R_p referred to the secondary.

$$R_p = R_q \left(\frac{L_1}{M}\right)^2 = R_q \frac{L_1}{L_2 k^2} \tag{9}$$

X_q is the detuning additional parallel reactance referred to the secondary.

$$X_p = X_q \left(\frac{L_1}{M}\right)^2 \tag{10}$$

In order that the detuning shall remain small, X_q must be large.

It is seen from the diagram how little R_q exceeds R_2 as long as R_2 remains large compared with the total leakage reactance $X_{2\lambda} = \omega L_2 (1-k^2)$. The quantity R_q decreases more and more slowly as R_2 gets smaller until at $R_2 = \omega L_2 (1-k^2)$ a minimum is attained after which it increases again. X_q decreases continuously, which means that the detuning increases steadily. When $R_2 = \omega L_2 (1-k^2)$, R_q becomes equal to $2 R_2$. When R_2 is large compared with $\omega L_2 (1-k^2)$, X_q is very large; the circuit tuning is practically the same as at no load. A decrease of R_2 appears as an additional parallel connected inductance and necessitates a re-adjustment of the tuning by an increase of C_1, this increase being in the ratio $\frac{2-k^2}{2(1-k^2)}$, for $R_2 = \omega L_2 (1-k^2)$ attaining finally the value $\frac{1}{1-k^2}$ when, for $R_2 = 0$, the inductance in parallel with the circuit is equal to the entire leakage inductance.

In order, with a given R_p, that is with a given $R_q \approx R_2$ and $\left(\frac{L_1}{M}\right)^2$, to keep the detuning to a minimum (independent of the variations of the coupling), i. e. to ensure as high as possible a value for X_q, $\omega L_2 (1-k^2)$ must be as small as possible. With $M = k\sqrt{L_1 L_2}$, $L_2 k^2$ is fixed and constant; using the figure of merit of the circuit $Q = \frac{R_q}{\omega L_1}$, equation (7) may be re-written in the following form:

$$Q = \frac{R_p}{\omega L_1} = 2\frac{1-k^2}{k^2} \tag{11}$$

It follows from this that under optimum conditions, i. e. when $\omega L_2 (1-k^2)$ is made equal to R_2, a definite value of k is necessary in order to obtain any particular circuit loading. The value of k is the minimum necessary, in that with other than optimum conditions stronger couplings are necessary. Then

$$k_{min} = \sqrt{\frac{2}{Q+2}} \tag{12}$$

The following are the minimum values of k corresponding to different values of Q.

Q	=	5	10	20	50	100
$k_{min.}$	=	0·53	0·41	0·30	0·19	0·14

Furthermore, the diagram Fig. 4 shows the effect of variation of the leakage reactance $X_{2\lambda} = \omega L_2 (1-k^2)$.

When R_2 is large compared with $X_{2\lambda}$ a reduction of $X_{2\lambda}$ results in a small reduction of R_q and in a considerable increase in X_q, i. e. the tuning approximates to the no-load tuning.

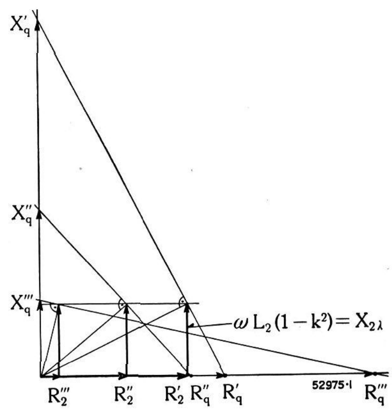

Fig. 4. — Vector determination of the parallel resistance and inductance referred to the secondary side $\left(\text{constant conversion ratio } \left(\frac{L_1}{M}\right)^2\right)$ with pure ohmic resistance load.

When R_2 equals $\omega L_2 (1-k^2)$ a reduction of $X_{2\lambda}$ results in a direct reduction of R_q without reducing X_q. Hence, in this case only the transformation ratio decreases with $X_{2\lambda}$, i. e. influencing only R_p, whilst R_2 is affected only by the tuning (90^0 phase displacement).

When R_2 is small compared with $\omega L_2 (1-k^2)$ a reduction of $X_{2\lambda}$ results in a considerable reduction of R_q and X_q. The tuning is affected in the opposite sense to that when R_2 is large compared with $\omega L_2 (1-k^2)$.

(c) *Load consisting of a resistance and a reactance in series.*

The addition of a series reactance X_{2s} has the same effect as a variation of $X_{2\lambda}$. Upon substituting

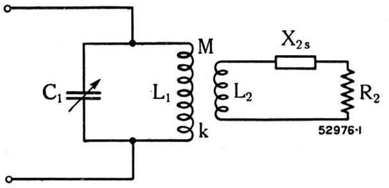

Fig. 5. — Diagram of a resistance and reactance load.

$\omega L_2 + X_{2s}$ for ωL_2 in the above calculation, the expression for the conversion ratio becomes

$$\frac{R_p}{R_2} = \frac{L_1}{L_2 k^2} \left[1 + \left(\frac{\omega L_2 (1-k^2) + X_{2s}}{R_2}\right)^2\right] \quad (13)$$

(X_{2s} in series with L_2 in the denominator cancels out.)

As might be expected, X_{2s} does not affect the no-load transformation ratio $\frac{L_1}{L_2 k^2}$, but appears only in series with the leakage inductance.

When X_{2s} is caused by an inductance L_2', this latter can, of course, be regarded as belonging to L_2, whereupon, however, a correspondingly smaller value is obtained for k. Since M remains constant, k now becomes

$$k = \frac{M}{\sqrt{L_1 (L_2 + L_2')}}$$

Inserting these values in the formula without X_{2s} gives exactly the same result as can readily be found by trial.

If X_{2s} is a capacity, it is possible to compensate $X_{2\lambda}$

$$X_{2s} = \frac{1}{\omega C_2} = X_{2\lambda} = \omega L_2 (1-k^2)$$

or

$$\omega C_2 = \frac{1}{\omega L_2 (1-k^2)} \quad (14)$$

R_q may then be reduced to R_2. The greater the ratio $\frac{\omega L_2 (1-k^2)}{R_2}$, the greater is the attainable reduction. Over-compensation causes R_q to increase again in a similar manner. The curves reproduced in Fig. 6 show the way in which the relative loading of the circuit expressed in terms of R_q varies with the capacitive reactance (scale expressed as multiple of R_2) when the ratio $\frac{\omega L_2 (1-k^2)}{R_2}$ is taken as the variable parameter and when the origin of all curves

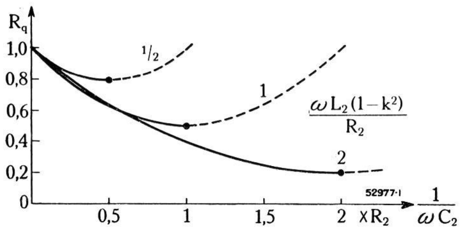

Fig. 6. — Relative loading of the circuit as a function of the series capacitive reactance with different degrees of coupling.

is made to coincide with the value 1. These curves give in this way a clear picture of the reduction caused by the series capacity.

If it is required by means of this compensation to cover a given range of the conversion ratio, the values must be determined in the following manner:

The minimum conversion ratio (smallest value of R_p for a given R_2) becomes

$$\frac{R_{p\,min}}{R_2} = \frac{L_1}{L_2 k^2} = \left(\frac{L_1}{M}\right)^2 \quad (15)$$

From this M or $L_2 k^2$ may be obtained.

The factor by which the maximum transformation ratio exceeds the minimum ratio (the range factor) is

$$\frac{R_{p\,max}}{R_{p\,min}} = \frac{R_q}{R_2} = 1 + \left(\frac{\omega L_2 (1-k^2)}{R_2}\right)^2 \quad (16)$$

Knowing the value of $L_2 k^2$, L_2 and k may then be determined from this equation. *The smaller k and the larger L_2 (the poorer the coupling), the larger is the range covered.*

(d) *Load consisting of a resistance and a reactance in parallel.*

If the load $\mathfrak{R}_2$ constitutes an oscillatory circuit, its reactance also affects the transformation ratio. The tuning should, as usual, affect only the reactive parallel component, the active resistance R_2 remaining constant. Capacity tuning allows the leakage inductance to be compensated, thus enabling R_p to be reduced. In order to gauge the effect, it is best to convert the parallel connected R_2 and $\frac{1}{\omega C_2}$ (when C_2 represents the resulting capacity) into the equivalent simple series circuit $R_2' + j X_2'$ which may then be inserted in the previously deduced formulae. Then

$$R_2' = \frac{R_2}{1 + (\omega C_2 R_2)^2}$$

$$X_2' = -\frac{\omega C_2 R_2^2}{1 + (\omega C_2 R_2)^2}$$

Substituting these values and effecting a few transformations yields

$$R_p = \frac{R_2 L_1}{L_2 k^2}\left(\frac{\omega L_2 (1-k^2)}{R_2}\right)^2 \left[1 + \left(\frac{R_2}{\omega L_2 (1-k^2)} - \omega C_2 R_2\right)^2\right] \tag{17}$$

In this formula the expression in the square brackets determines by how much R_p may be reduced when under the influence of C_2. Comparing this with the corresponding bracket for the series connection according to formula (13), which may be written

$$\left[1 + \left(\frac{\omega L_2 (1-k^2)}{R_2} - \frac{1}{\omega C_2 R_2}\right)^2\right]$$

shows immediately the close analogy of the two formulae. Since the expressions containing the letter symbols stand in reciprocal relation to each other, a diagram with exactly the same curves as those of Fig. 6 should be obtained for the parallel connection according to Fig. 7, if the reciprocal value ωC_2 is plotted (expressed in terms of $\frac{1}{R_2}$) along the abscissae and the reciprocal of the corresponding value of Fig. 6 is chosen as the variable parameter. The curves are again drawn to a scale of multiples of R_q with the origin of all curves at unity.

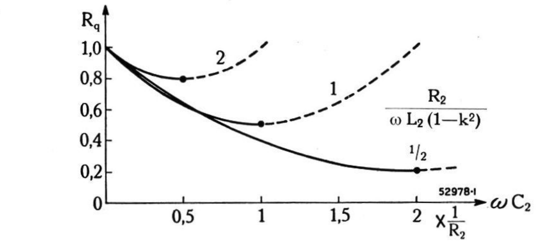

Fig. 7. — Relative loading of a circuit as a function of the susceptance with different degrees of coupling.

Contrary to the case with series capacity regulation, the smaller the leakage reactance, the greater the regulation range.

The minimum value of R_p is again attained when

$$\omega C_2 = \frac{1}{\omega L_2 (1-k^2)}$$

and its value is then

$$R_{p\,min} = \frac{\omega^2 L_1 L_2}{R_2} \frac{(1-k^2)^2}{k^2} \tag{18}$$

The minimum conversion ratio then becomes

$$\frac{R_{p\,min}}{R_2} = \frac{\omega^2 L_1 L_2}{R_2^2} \frac{(1-k^2)^2}{k^2} \tag{19}$$

A better picture of the phenomena taking place and a good idea of the relative load conditions is obtained by drawing for the case of a parallel load a vector diagram similar to that of Fig. 4. The locus curve of the impedance vector of a resistance R_2 in parallel with a variable condenser is according to Fig. 8 a semi-circle which must be substituted for

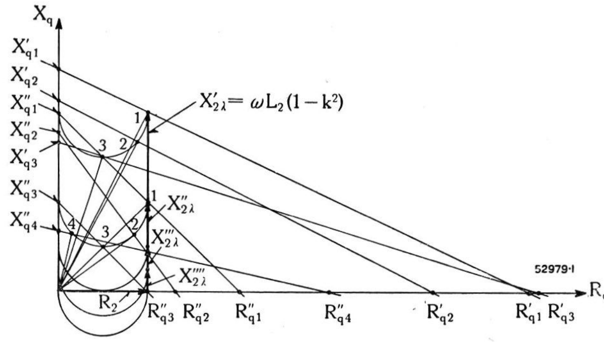

Fig. 8. — Vector determination of the parallel resistances and inductance referred to the secondary side (constant transformation ratio $= \left(\frac{L_1}{M}\right)^2$) with parallel ohmic resistance and capacitive loads.

R_2 in the previous diagram. The tip of the leakage inductance vector then also describes such a circle, which is, however, displaced by an amount $X_{2\lambda}$. As shown by the construction drawn for a few points in the two cases $\frac{\omega L_2 (1-k^2)}{R_2} = 1$ and 2, R_q in accordance with the curve Fig. 7 first decreases, afterwards increasing again, X_q undergoing a similar variation.

(e) *Comparison of the series and parallel capacity circuits.*

In order to compare the relative advantages and disadvantages of the series and parallel methods of connection, it is necessary to consider different cases occurring in practice.

The first interesting comparison is in regard to *the additional capacity required to cover a given range of load R_p (i. e. R_q).* If, for instance, the latter is taken as 1 to 5 (i. e. $0 \cdot 2$ to 1), there is required a ratio $\frac{\omega L_{2s} (1-k_s^2)}{R_2} = 2$ (or generally $= a$) and a variation of the capacitance $\frac{1}{\omega C_2}$ of 0 to 2 R_2 corresponding to capacitance variation of ∞ to $\frac{1}{2\,\omega R_2}$. Similarly for the parallel case a ratio

$$\frac{\omega L_{2p} (1-k_p^2)}{R_2} = \frac{1}{2} \left(\text{or generally} = \frac{1}{a}\right)$$

and susceptance variation ωC_2 of 0 to $\frac{2}{R_2}$ corresponding to a capacity variation of 0 to $\frac{2}{\omega R_2}$.

The inverse sense of the capacity variation is particularly striking. In regard to the size of the capacity required to make R_p a minimum, the following considerations apply.

The physical size is fixed by the VA rating. Now in order to carry out the comparison basing on the same load resistance, on a constant operating voltage $\mathfrak{U}_2$ and a constant operating current $\mathfrak{J}_2$, it is necessary to connect in the first case a capacitance of $2\,R_2$ (generally $a \cdot R_2$) in series, and in the second one of $\frac{R_2}{2}$ $\left(\text{generally } \frac{R_2}{a}\right)$ in parallel.

1st case $\mathfrak{J}_c = \mathfrak{J}_2$ $\mathfrak{U}_c = \mathfrak{J}_2 \cdot a R_2$ $\underline{\mathfrak{U}_c \cdot \mathfrak{J}_c = \mathfrak{J}_2^2 \cdot a R_2}$

2nd case $\mathfrak{U}_c = \mathfrak{U}_2$ $\mathfrak{J}_c = \frac{a\,\mathfrak{U}_2}{R_2}$ $\mathfrak{U}_c \cdot \mathfrak{J}_c = \mathfrak{U}_2^2 \frac{a}{R_2}$

putting $\mathfrak{U}_2 = \mathfrak{J}_2 \cdot R_2$ gives $\underline{\mathfrak{U}_c \cdot \mathfrak{J}_c = \mathfrak{J}_2^2 \cdot a R_2}$

The value of the capacity is exactly the same in both cases. It remains to be seen what the effect of range variation is. In both cases an increase of R_p with a usually constant oscillatory circuit voltage means a reduction of the load R_2. Hence, if the capacity variation is achieved in the second case by means of an ordinary rotating vane condenser, its voltage stressing $\mathfrak{U}_c = \mathfrak{U}_2$ is subject to reduction only, and dimensioning it for the condition R_p = minimum gives an adequate margin of safety. In the first case the same type of condenser, if used for regulating purposes, would have to be made very much larger. On the other hand, regulation could here be effected by reducing the distance between plates. The capacity increases, however, inversely with the distance between plates, hence, with constant current the voltage which varies inversely with the capacity, varies then in direct proportion to the distance. Taking into consideration the decreasing current, the voltage safety margin can in this manner also be retained here when regulating, and dimensioning the condenser for the normal operating point of R_p = minimum, gives here also the correct size. *Hence, except for the different design, there is no difference in the physical size of the condensers required for the two connections.*

It remains to be seen whether appreciably different coil arrangements are required by the two alternatives. In both cases $R_{p\,min}$ must be the same. The inductance L_1, which is considered as forming part of the oscillating circuit, must then be regarded as being constant and fixed by other conditions (Q of the circuit). The corresponding formulae are then

$$1^{st} \text{ case} \quad R_{p\,min} = \frac{R_2 L_1}{L_{2s} k_s^2} \qquad \text{(cf. 15)}$$

$$2^{nd} \text{ case} \quad R_{p\,min} = \frac{\omega^2 L_1 L_{2p}}{R_2} \frac{(1-k_p^2)^2}{k_p^2} \qquad \text{(cf. 18)}$$

On eliminating the constant quantity ωL_1, by using the expression

$$Q_{min} = \frac{R_{p\,min}}{\omega L_1}$$

$$1^{st} \text{ case} \quad Q_{min} = \frac{R_2}{\omega L_{2s}} \cdot \frac{1}{k_s^2} \qquad (20)$$

$$2^{nd} \text{ case} \quad Q_{min} = \frac{\omega L_{2p}}{R_2} \frac{(1-k_p^2)^2}{k_p^2} \qquad (21)$$

Apart from the factor $(1-k_p^2)^2$ the two formulae differ in that the ratios $\frac{R_2}{\omega L_{2s}}$ and $\frac{\omega L_{2p}}{R_2}$ stand in reciprocal relation one to the other. Hence, the condition of equal regulation range is:

$$\frac{\omega L_{2s}(1-k_s^2)}{R_2} = a = \frac{R_2}{\omega L_{2p}(1-k_p^2)}$$

Combining these last three equations leads to the very simple condition

$$\underline{k_s = k_p}$$

The coupling must be exactly the same in both cases, i. e. the arrangement of the coils must in both cases be the same. The essential difference between the two connections lies in the fact that L_2 must be considerably larger for the series circuit than for the parallel circuit. Moreover, with the series circuit, the voltage across L_2 is larger, but the current correspondingly smaller than with the parallel circuit. From the point of view of manufacture, this means that with the series connection more turns of smaller cross section have to be accommodated in the same space (k = constant) than with the parallel connection.

It should not be overlooked that with the type of regulation considered, every alteration of the setting of the condenser C_2 requires a re-adjustment of the circuit tuning. In both cases, however, the tuning approaches the same point at the two ends of range for $R_{p\,max.}$ and $R_{p\,min}$, as can be seen from a glance at the vector diagram.

A similar result is obtained if the two connections are compared with regard to their suitability for producing a minimum R_p, i. e. the corresponding Q independently of any range of regulation.

Significance attaches to the problem when the required Q is so small that a transmission without additional capacity becomes impossible. Without capacity the attainable Q is given by the relation

$$Q_{min} = 2\,\frac{1-k_o^2}{k_o^2} \qquad \text{(cf 11)}$$

The problem also crops up when k_o for some reason or other (spacing necessitated by high voltage) cannot be made sufficiently high. In such a case k may be considered as being more or less fixed. The following formulae then again apply to the two capacity circuits:

$$\text{Series connection } Q_{min} = \frac{R_2}{\omega L_{2s}} \frac{1}{k_s^2} \quad (20)$$

$$\text{Parallel connection } Q_{min} = \frac{\omega L_{2p}}{R_2} \frac{(1-k_p^2)^2}{k_p^2} \quad (21)$$

The capacity connections enable, therefore, by means of the factors $\frac{R_2}{\omega L_{2s}}$ and $\frac{\omega L_{2p}}{R_2}$ an improvement to be obtained over the factor 2 in the case with no capacity.

But the investigations of the previous case have shown that with constant k, both capacity connections lead to the same size of condenser for a given value of Q_{min}.

Once again, therefore, comparison shows the two connections to be equivalent with exception to the fact that with series connection more turns of smaller cross section are required for L_2 than with the parallel connection. Which alternative is the more advantageous in any particular case will depend on the available manufacturing facilities and on the absolute value of L_2 and hence on the operating frequency: With short waves, where L_2 may be so small that a single turn already provides too much inductance, it will be more convenient to make use of the higher inductance of the series connection than with long waves.

In the third comparison a circuit is considered to which particular importance attaches in view of the large range of variation of the transformation ratio, namely the circuit with variable coupling achieved either by pivoted or swing mounting of the coils. Since in such cases the coupling may be reduced down to zero, the limiting value of R_p lies at infinity and the transformation ratio can be reduced down to no load. Once again, in order to be able to effect a proper comparison, the same value of $R_{p_{min}}$ must be based upon in both cases. This means the comparison consists of an extension of the results of the previous comparison. The only difference is that the coupling is variable, which imposes certain limitations in regard to the coupling factor: This can no longer take on such high values. (With pivoted coils about 0·2 to 0·3.) It remains to be seen what distinctions are shown by the two methods of variation in practice. Here the series connection shows up to considerably better advantage, namely in regard to variation of the out-of-phase component of the load, or expressed in other words, in regard to the necessity of readjusting the tuning of the oscillatory circuit with variation of the coupling. *With the series connection the two adjustments may be effected practically independently, whereas, except in special cases, the parallel connection always implies a certain dependence of the coupling on the tuning.* These dependencies can be readily deduced from the vector diagram Figs. 4 and 8. It is noted first that for $k = 0$ the load circuit is completely independent of the oscillatory circuit, and hence that the latter should be tuned for no load. This adjustment may then be retained on establishing the coupling, provided there is no reactive parallel load. It follows from the above deductions that with the series connection the inductive leakage reactance loading $X_{2\lambda}$ is exactly compensated by the series capacity. The vectors $X_{2\lambda}$ of the Fig. 4 then become zero and the construction gives for X_q the value ∞, that is, the additional reactive loading becomes $= 0$. There is, it is true, a small remaining effect which, however, may be neglected in practice, provided $\omega L_2 (1-k^2)$ is not very large compared with R_2, because the compensation $X_{2\lambda} = \frac{1}{\omega C_2} = \omega L_2 (1-k^2)$ can only be regarded as fulfilled at maximum coupling. In any case, provision should be made to permit adjustment of C_2 in the most unfavourable case. With loose coupling the factor $(1-k^2)$ becomes larger and the compensation is lost. The variation is, however, very small. Thus the variation of this factor over the range $k = 0 \cdot 2$ to $k = 0$ is only for $0 \cdot 96$ to 1, i.e. only 4 %. The maximum reactive load which can only occur between the limits $k = 0$ and $k = 0 \cdot 2$, and hence at a point where the departure from perfect compensation is still smaller, will even in the case of $\omega L_2 (1-k^2) = 2 R_2$ be negligibly small. The construction in this diagram with about 2 % compensation error shows that in this case X_q is still 25 times greater than R_q, which is hence practically equal to R_2.

Very different are the conditions with parallel connection. Fig. 9 shows the construction of X_q and R_q, when to obtain maximum coupling $\omega L_2 (1-k^2)$ is made equal to $\frac{R_2}{2}$ (giving the same $R_{p_{min}}$ as a series connection with $\omega L_2 (1-k^2) = 2 R_2$). As can be seen X_q is only about twice as large as R_q. This means that with maximum coupling the no-load tuning is too much disturbed to be capable of being retained. If, on the other hand, the tuning is correctly adjusted for maximum coupling, a correspondingly large capacitive detuning occurs upon loosening the coupling to $k = 0$.

There does exist a possibility of obtaining the same independency of the coupling with the parallel connection as with the series if C_2 instead of being adjusted for R_p = min. is made such that the resulting load vector Z_q lies along the resistance axis as shown dotted and denoted by the letters C_2' Z_q', R_q and X_q' in Fig. 9. C_2' is then half as large as C_2. Such a procedure is only possible when the circle

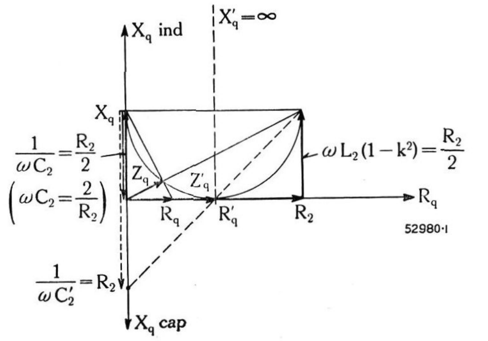

Fig. 9. — Equivalent parallel load X_q and R_q for R_p = min., i. e. X_q' and R_q' for zero detuning when $\omega L_2 (1-k^2) = R_2/2$.

touches or intersects the resistance axis, that is, when $\omega L_2 (1-k^2)$ is smaller than $R_2/2$. The advantage of independency is, however, obtained at the cost of sacrificing the achievment of $R_{p_{min}}$ (in the present example $R_p' = 2\,R_p$) and putting up with a more complicated process for adjusting C_2.

The comparison would be incomplete without the mention of a further advantage of the series connection over the parallel connection: A variation of the load resistance R_2 is transmitted without distortion of either amplitude or phase to the oscillatory circuit. This follows simply from the fact that with practically complete compensation

$$\text{i. e. where} \left(X_{2\lambda} = \frac{1}{\omega C_2}\right), \; R_2 = Z_q.$$

The conditions are much less favourable with parallel connection, as is shown by the diagrams of Figs. 10 and 11. According to Fig. 10, if C_2 is adjusted for a maximum possible load (R_p = min.), the load resistance of the circuit is reduced upon increasing the

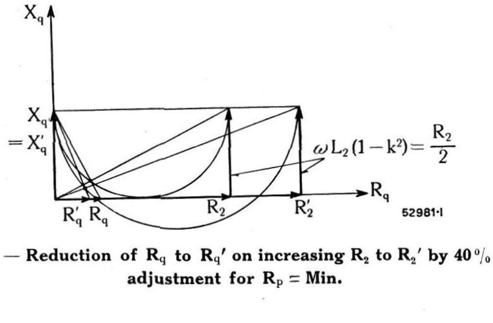

Fig. 10. — Reduction of R_q to R_q' on increasing R_2 to R_2' by 40 % with adjustment for R_p = Min.

external resistance R_2 (a phase displacement of R_2 would produce changes in X_q and R_q).

Fig. 11 shows the changes which would occur if the adjustment of C_2 were such that no readjustment

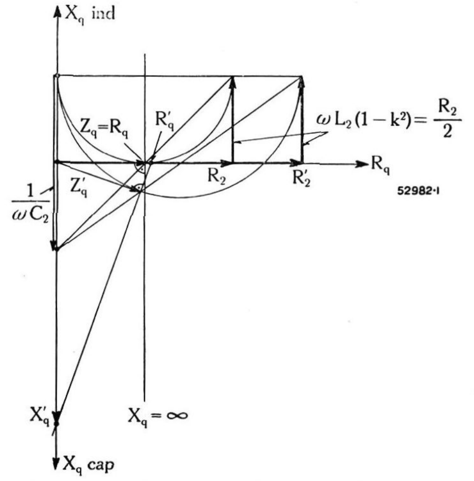

Fig. 11. — Increase of R_q to R_q' and creation of a reactive load X_q' upon increasing R_2 to R_2' by 40 % when adjusted for zero detuning.

of the circuit tuning were necessary. In such a case, not only does R_q vary with R_2 in some manner difficult to follow, but also the alteration of X_q from infinity to X_q' introduces a capacity circuit load.

III. TERMINAL SIDE.

(a) *Symbols for terminal side:*

L_1	Coupling inductance
L_2	Oscillatory circuit inductance
M	Mutual inductance
C_2	Oscillatory circuit capacity
C_{res}	Resonance capacity
ΔC	"De-tuning" capacity
$\mathfrak{Z}_1$	Vector value of the impedance at the coupling coil terminals
Z_1	Absolute value of the impedance at the coupling coil terminals
$\mathfrak{Z}_2$	Load impedance at L_2
R_p	Resulting parallel resistance of $\mathfrak{Z}_1$
R_2	Parallel load resistance in oscillatory circuit
k	Coupling factor
ü	Transformation ratio
ω	Circular velocity
$\mathfrak{U}_1\, U_1$	Vector and r. m. s. value of the voltage at the coupling coil
$\mathfrak{U}_2\, U_2$	Vector and r. m. s. value of the oscillatory circuit voltage
$\mathfrak{I}_1\, I_1$	Vector and r. m. s. value of the current in the coupling coil
$\mathfrak{I}_2\, I_2$	Vector and r. m. s. value of the current in the oscillatory circuit inductance.

(b) *Load connections:*

As in the case of the input side the relations which mainly interest us are the way in which the primary impedance and the transformation ratio depend on the secondary load, which latter consists mainly of the circuit capacity C_2. The designations of the principal characteristic quantities are indicated in the diagram Fig. 12.

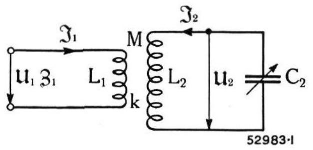

Fig. 12. — An oscillatory circuit coupled to a link line.

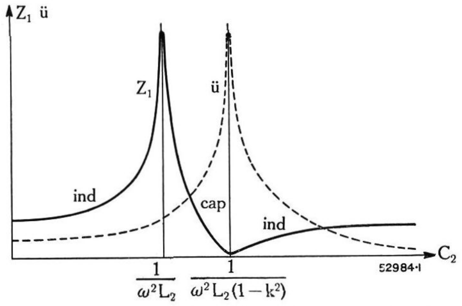

Fig. 13. — Input impedance Z_1 and transformation ratio ü as a function of the circuit capacity.

According to equation (21) the following relation holds good for a transformer loaded on the secondary side with a resistance R_2.

$$\mathfrak{Z}_l = \frac{j\omega L_1 R_2 - \omega^2 L_1 L_2 (1-k^2)}{R_2 + j\omega L_2} \tag{21}$$

Instead of R_2, there must now be indicated $\frac{1}{j\omega C_2}$.

$$\mathfrak{Z}_1 = \frac{\frac{\omega L_1}{\omega C_2} - \omega^2 L_1 L_2 (1-k^2)}{j\left(\omega L_2 - \frac{1}{\omega C_2}\right)}$$

$$\mathfrak{Z}_1 = j\omega L_1 \frac{\frac{1}{\omega C_2} - \omega L_2 (1-k^2)}{\frac{1}{\omega C_2} - \omega L_2} \tag{22}$$

The relation which is shown in curve form in Fig. 13, which, however, allows for a certain damping resistance, presents the following singularities:

For $C_2 = 0$ $\quad \mathfrak{Z}_1 = j\omega L_1$

$C_2 = \frac{1}{\omega^2 L_2}$ $\quad \mathfrak{Z}_1 = \infty$ Resonance

$C_2 = \frac{1}{\omega^2 L_2 (1-k^2)}$ $\quad \mathfrak{Z}_1 = 0$ maximum transformation ratio (see below)

$C_2 = \infty$ $\quad \mathfrak{Z}_1 = j\omega L_1 (1-k^2)$

between $C_2 = 0$ and $\frac{1}{\omega^2 L_2}$ $\quad \mathfrak{Z}_1$ is inductive

between $C_2 = \frac{1}{\omega^2 L_2}$ and $\frac{1}{\omega^2 L_2 (1-k^2)}$ $\quad \mathfrak{Z}_1$ is capacitive

between $C_2 = \frac{1}{\omega^2 L_2 (1-k^2)}$ and ∞ $\quad \mathfrak{Z}_1$ is inductive

The distance ΔC between $\mathfrak{Z}_1 = \infty$ and 0 becomes

$$\Delta C = \frac{1}{\omega^2 L_2 (1-k^2)} - \frac{1}{\omega^2 L_2}$$

$$\Delta C = \frac{1}{\omega^2 L_2} \frac{k^2}{1-k^2}$$

or

$$\Delta C = C_{res} \frac{k^2}{1-k^2} \tag{23}$$

For calculating the voltage transformation ratio $ü = \frac{\mathfrak{U}_2}{\mathfrak{U}_1}$ it is most convenient to start from the transformer equations:

$$\mathfrak{U}_1 = \mathfrak{J}_1 \cdot j\omega L_1 + \mathfrak{J}_2 j\omega M$$
$$\mathfrak{U}_2 = \mathfrak{J}_2 \cdot j\omega L_2 + \mathfrak{J}_1 j\omega M$$

To these should be added the equation of the applied load.

$$\mathfrak{U}_2 = -\mathfrak{J}_2 \frac{1}{j\omega C_2}$$

From these three equations it is easy after a few transformations to deduce the following equation:

$$\frac{\mathfrak{U}_2}{\mathfrak{U}_1} = \frac{M}{L_1 - \omega^2 C_2 (L_1 L_2 - M^2)}$$

or

$$\frac{\mathfrak{U}_2}{\mathfrak{U}_1} = k\sqrt{\frac{L_2}{L_1}} \frac{1}{1 - \omega^2 C_2 L_2 (1-k^2)}$$

This relation is also depicted in Fig. 13.

Then for

$C_2 = 0$ $\quad \frac{\mathfrak{U}_2}{\mathfrak{U}_1} = k\sqrt{\frac{L_2}{L_1}} = \frac{M}{L_1}$

$C_2 = \frac{1}{\omega^2 L_2}$ $\quad \frac{\mathfrak{U}_2}{\mathfrak{U}_1} = \frac{1}{k}\sqrt{\frac{L_2}{L_1}} = \frac{L_2}{M}$

$C_2 = \frac{1}{\omega^2 L_2 (1-k^2)}$ $\quad \frac{\mathfrak{U}_2}{\mathfrak{U}_1} = \infty$

$C_2 = \infty$ $\quad \frac{\mathfrak{U}_2}{\mathfrak{U}_1} = 0$

For practical purposes it is convenient to use here the conversion ratio which is better suited to practical conditions and which is represented by the ratio of the voltages from primary to secondary sides. To establish the relation with the input side, it is necessary to take the reciprocal and to raise it to the power of two. For any general load, $\mathfrak{Z}_2$ instead of $\frac{1}{j\omega C_2}$, C_2 must be replaced by $\frac{1}{j\mathfrak{Z}_2}$. The resulting expression is then

$$\frac{\mathfrak{U}_2}{\mathfrak{U}_1} = k\sqrt{\frac{L_2}{L_1}}\,\frac{1}{1+\frac{j\omega L_2}{\mathfrak{Z}_2}(1-k^2)} = \frac{M}{L_1+\frac{j\omega(L_1L_2-M^2)}{\mathfrak{Z}_2}}$$

If R_2 is substituted for $\mathfrak{Z}_2$, the absolute value calculated, the reciprocal taken and raised to the power of two, we again get formula (8) for $\frac{R_P}{R_2}$, giving the conversion ratio of a single ohmic loading resistance from the secondary to the primary side. $R_p = \ddot{u}^2 R_2$ where $\ddot{u} = \frac{U_1}{U_2}$. If a relatively large ohmic resistance R_2 is connected in parallel with C_2, it is transmitted with the above transformation ratio to the primary side.

$$R_p = \left(\frac{U_1}{U_2}\right)^2 \cdot R_2$$

Thus, for example, in the case of resonance

$$C_2 = \frac{1}{j\omega L_2} : R_p = \left(\frac{M}{L_2}\right)^2 R_2$$

In the diagram Fig. 14 there is drawn in addition to the curve of X_p given by equation (22) also the curve thus obtained for the effective parallel resistance.

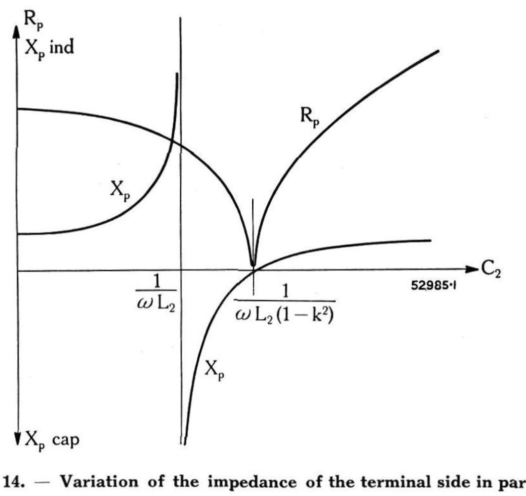

Fig. 14. — Variation of the impedance of the terminal side in parallel components.

For certain purposes it is more convenient to illustrate the variation of the impedance in the form of vector locus curves, as has been done in the case of Fig. 15. Since the vector diagram contains the series components of the impedance, it is necessary to convert the latter from the parallel components of Fig. 14. The transformation may be effected point by point since the momentary value of the locus vector for any corresponding pairs of values drawn along the X and R axes is equal to the perpendicular to the connecting

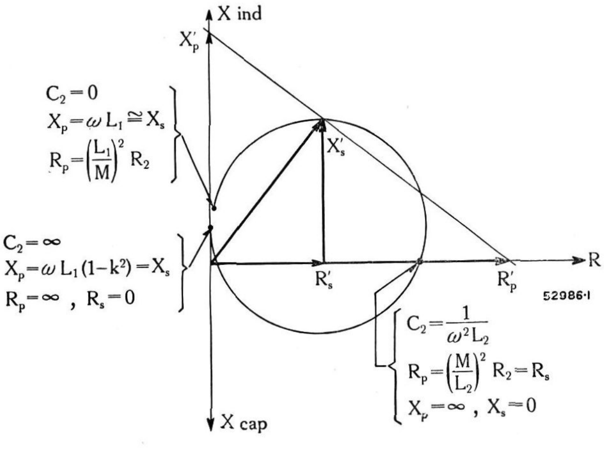

Fig. 15. — Variation of the impedance of the terminal side shown as a locus vector.

line. If in a case occuring in practice in which R_2 (load caused by the grid of the next valve) is known, the primary resistance is fixed (surge resistance of link line), a certain definite transformation ratio $\frac{L_2}{M} = \frac{1}{k}\sqrt{\frac{L_2}{L_1}}$ must be achieved. Since L_2 is usually determined by other requirements (band width requirements) and cannot be freely chosen, $k^2 L_1$ must, therefore, have a definite value. *The question of the subdivision, i.e., whether L_1 should be made large and k small or vice versa, is settled in favour of making k as nearly as possible equal to 1 and hence L_1 small, because in this way the influence on the tuning up to the short circuit point $\Delta C = C_{res}\frac{k^2}{1-k^2}$ is large.* This has the result that when tuning about the point of C_{res}, ü varies only slightly with C_2. If this is not the case, a tuning point could be found which would not give pure ohmic loading, in that when C_2 is increased to a little more than C_{res}, $\mathfrak{Z}_1$ on the line certainly does decrease somewhat due to the capacity component introduced, which renders poorer the matching to the preceeding stage, but at the same time, ü increases, which compensates the drop in voltage on the line.

IV. COMBINED OPERATION OF BOTH SIDES.

For correct operation of the circuits on both sides, the transformation at the terminal side must be so adjusted that the given load resistance, varied from the line, is transformed into a resistance equal to the surge resistance. At the input side, the resistance must in turn be converted to the necessary required value. *In this manner stationary waves on line are avoided, the voltage remaining constant all along the line and the transmission being independent of the length of this line.* If the terminal resistance does not correspond to the surge resistance, this fault is transmitted in various ways to the input end, depending on the length of the line. Fundamentally, there is a rotation of the faulty vector with respect to the surge resistance vector, as a function of length of line about the tip of the surge resistance vector, there being a full rotation for a line length equal to a half wave length. If, for instance, the terminal resistance is somewhat less than the surge resistance, it is transformed in the case of a line length of $\lambda/8$ into an input end resistance with a slightly lagging phase angle. (Series inductance approximately equal to the resistance error.)

When the line length is $\lambda/4$, the resistance becomes ohmic again, but it then exceeds the surge resistance by the same amount by which it is less than the surge resistance at the output end (expressed in percentage). After a line length of $3\lambda/8$, the input end resistance is again equal to the surge resistance, but it is now at a capacitive angle attaining again for line length $\lambda/2$ the same value as the terminal resistance.

If now it is desired to investigate how the various changes imposed by service or other conditions occurring at the terminal end of line are transmitted to the input end, complex and obscure relations result. *It is simpler to consider the combined behaviour for the case of a short line, such as usually occurs in the coupling of two amplifying stages in a transmitter.*

The diagram Fig. 16 then shows the relations for the basic connection of Fig. 1 *for the case* $\omega L_2 (1-k^2) = 2 R_2$ *on the input side.* It differs from the diagram of Fig. 8 only in that the circle under the tip of $\omega L_2 (1-k^2)$ is no longer tangential, as it must be when the terminal circuit is directly connected into the line, but as shown in Fig. 15 it is somewhat displaced, this being caused by the leakage inductance in the coupling of the terminal circuit. This results in the minimum value of R_p not lying exactly in the same position as it would have to be according to Fig. 7: the effect is, however, small. The corresponding diagram values are R_q' X_q' $\mathfrak{Z}_1'$. They belong to the tuning point P'. *As can be seen, the resulting terminal resistance* $\mathfrak{Z}_1$ *of the line is not a pure ohmic but a capacitively displaced*

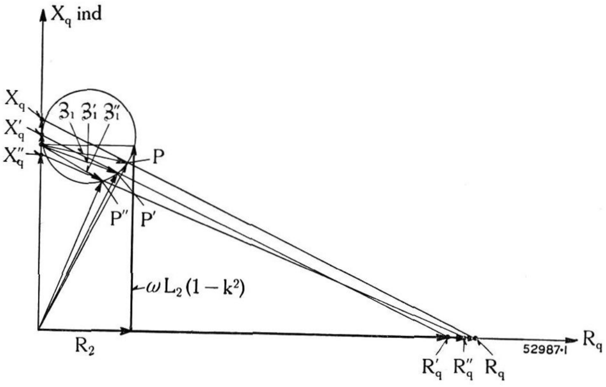

Fig. 16. — **Vector diagram of the coupling connection with a short line for $\omega L_2 (1-k^2) = 2 R_2$.**

resistance, i. e. the maximum loading of input circuit occurs when the tuning of the terminal circuit is disturbed by a slight capacitance. If the circuit tuning at this point is shifted slightly inductively with respect to the point P or capacitively with respect to the point P'', R_q becomes greater in both cases, and therefore the load and with it the voltage in terminal circuit decreases. When R_p at the input circuit is correctly matched to the preceeding amplifying valve, this change has no noticeable effect on the load. The adjustment is then relatively insensitive. This is particularly advantageous in that tuning can be carried out by adjusting first the input side when the terminal side is still quite out of tuning and that after adjusting the latter, it is not necessary to readjust the input side which would involve a readjustment of the terminal side (reciprocal retuning). (The criterion herefor is the correspondence of X_q' with X_q when the terminal circuit is completely out of tune.)

Specially noteworthy is a characteristic which conversely one might expect by intuition, namely *that the correction at the input circuit of a reduction of capacity in the terminal circuit also involves a reduction of capacity.*

A reduction of capacity causes an inductive phase shift of the tuning point of the terminal circuit, i. e. from P' to P. This causes a variation of the reactance loading at the input circuit of X_q' to X_q, i. e. the parallel connected inductance becomes larger. In order that the tuning shall be maintained, the capacitance must increase correspondingly, i. e. the capacity must be reduced.

Considerably different are the conditions when $\omega L_2 (1-k^2) < R_2$, for instance, if $\omega L_2 (1-k^2) = R_2/2$ as illustrated in the case of Fig. 17. It is

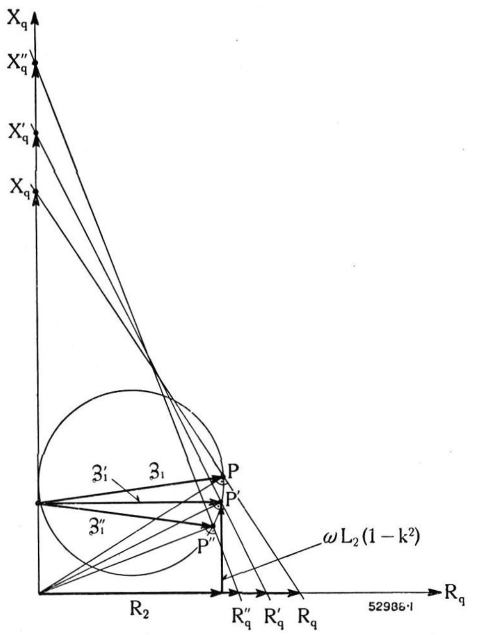

Fig. 17. — Vector diagram of the coupling connection with a short line for ωL_2 $(1-k^2) = R_2/2$. Ohmic loading of the line.

assumed here that the tuning may be regulated at the point P' by the aid of some instrument or other, and that the matching has been affected on the input side to the value of the resistance R_q'. Maximum voltage is then attained in the terminal circuit only on the basis of matching, since, as can be seen on the figure, R_q' no longer represents the resistance minimum. The reversed order of X_q X_q' and X_q'' as compared with Fig. 16 shows that for $\omega L_2 (1-k^2) < R_2$ the mutual detuning is also in the opposite direction, i. e. *that a reduction of capacity in the terminal circuit must now be compensated by a capacity increase in the input circuit.*

If no attempt is made at an artificial adjustment of the point P' in Fig. 17, and if the tuning is effected in the normal manner to a minimum value of R_p, the relationships are shown by Fig. 18. As can be seen from the deductions of page 427, R_q and hence also R_p are considerably smaller. On the other hand it is no longer possible to speak of a pure ohmic loading of the link line. The necessary large capacity adjustment of the terminal circuit prevents matching to the surge resistance of the line, and practical application is accordingly restricted to a very short link line. In calculating such a case, the disturbance of the tuning which reduces considerably the input resistance of the terminal circuit should be taken into account (ü of the terminal circuit approaches its maximum value). In regard to the sense in which the mutual disturbance of the tuning acts, the order of X_q, X_q' and X_q'' shows that in this case the tuning of the circuits must again be adjusted in the same sense.

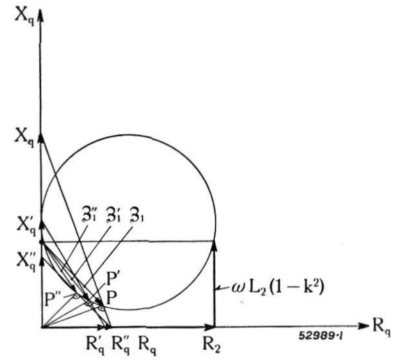

Fig. 18. — Vector diagram of the coupling connection with a short line for ωL_2 $(1-k^2) = R_2/2$. Tuning for R_p = min.

The consideration of the above practical cases shows that if correct adjustment is to be made only by means of the ordinary service instruments, without the aid of measuring bridges, when for instance adjustment to maximum load and when the length of the line is no longer negligible, satisfactory results can be obtained only in the case of $\omega L_2 (1-k^2)$ larger than R_2.

The conditions are very much more favourable when series capacity is used on the input side. The vector diagram then takes the form shown by Fig. 19. The magnitude of ωL_2 $(1-k^2)$ is here of no importance, as it is always compensated by the series capacity C_2. As can be seen, the tuning of the terminal circuit can be varied over a wide range without causing appreciable change of the loading resistance R_q. Variation occurs only to the extent by which the centre of the circle lies off the line of the vector $R_2 = \mathfrak{Z}_1'$. If the latter were to lie on R_2, every alteration of the tuning would cause the load resistance R_q to remain equal to R_2 (still assuming a short line). The order of sequence of X_q, X_q', X_q'' is such that the re-adjustment of the tuning of the two circuits is in opposite directions. *Apart from the reactive load of the link-line a disturbance of the tuning* *of the terminal circuit with a subsequent re-adjustment of the tuning of the input circuit results simply in a mutual exchange of capacity.*

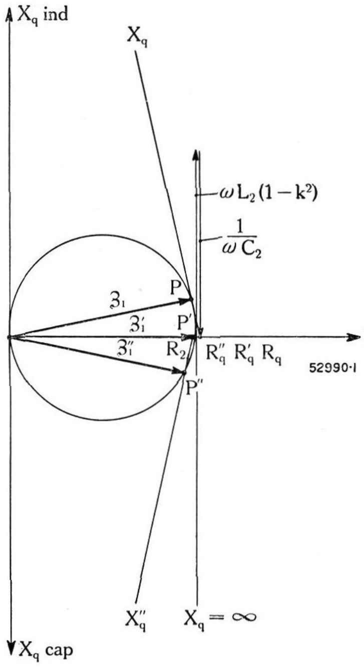

Fig. 19. — Vector diagram of the coupling connection with series capacity C_2 on the input side. Shown for a short line.

V. SUMMARY.

A system consisting of two oscillatory circuits connected by a link line is relatively frequently encountered for example in transmitters when it is constituted by the line to the aerial of in the connection of two consecutive amplifier stages. Many technical articles have appeared concerning the deduction of the formulae expressing the relationship between the magnitudes of the circuit elements and the electrical behaviour of the system. Such studies are, however, unsatisfactory to the designing and to the operating engineer, if they are not completed by an extensive analysis of the behaviour of the system in service. For regulating purposes it is necessary that certain variations shall be effected in service, which on the other hand should have a minimum disturbing effect on other adjustments, and according to the nature of the problem, the requirements may lead to entirely different premises for the dimensioning of the component elements. Such premises can only be deduced from the above mentioned formulae, when the manner in which the behaviour is affected by service factors has been fully investigated. The purpose of the present article is to carry out the exhaustive investigation which is necessary each time the problem of transmitter operation is considered.

The investigation is concerned with a system consisting of two oscillatory circuits which are connected by a link line which is inductively coupled to the two circuits.

On the input side, an exhaustive analysis is made of the real and reactive loading (damping and "detuning") of the circuit as a function of a pure ohmic resistance load as well as of such a load in series or in parallel with a variable condenser at the connecting point of the line, taking into account the effect of the coupling. It is seen that with a pure ohmic resistance the effective load resistance of the oscillatory circuit may not be reduced below a certain minimum, which for a given oscillatory circuit depends only on the coupling factor:

Thus a simple formula can be deduced showing the relationship between the coupling factor and the resulting Q of the oscillatory circuit when under load which shows that in order to achieve any particular Q, a certain minimum coupling is essential.

If for manufacturing or other reasons the required degree of coupling cannot be attained, an improvement may be achieved by connecting a condenser in series or in parallel on the input side. The series arrangement enables at the same time the detuning effect of the coupling to be reduced to zero. The loading of the circuit can be regulated down to no load by variation of the coupling. With a suitably dimensioned series condenser the load can be regulated, while the tuning remains practically entirely unaffected. If this is not considered necessary, mutual adjustment of the tuning condenser and of the series or parallel condenser enables an appreciable load range to be covered without altering the coupling. The attainable load range with series connection increases with decreasing coupling factor; with parallel connected capacity it increases with increasing coupling factor. Detailed comparisons between series and parallel connection for various interesting practical operating cases, show that the manufacturing material requirements are about the same in both cases, but that the series connection presents a number of important technical advantages.

On the terminal side it is of particular interest to know how the impedance at the connecting terminals and the voltage- and resistance transformation ratios vary with the circuit tuning. The impedance passes twice through a pure ohmic resistance, once as a resistance minimum, the resistance maximum representing the normal operating condition. The transformation ratio increases from the resistance maximum to the resistance minimum attaining its maximum value at this point.

For this reason there occurs a departure from a pure ohmic loading of the line with amplitude tuning, which increases as the two extreme values come closer together. The distance expressed as tuning capacity difference may be deduced as a simple function of the coupling factor, from which it follows that to avoid detuning, the coupling should be as strong as possible.

The phenomena arising out of the combined operation of the two circuits are very complex and are exceedingly difficult to grasp if the length of the line is not negligible compared with the wave length. Even with a short line a distinction must be made between different operating cases because of the varying phenomena accompanying them. Important in this respect is the fact whether the leakage reactance of the input side referred to the line is greater or smaller than the transmission resistance. In the first case there is, with amplitude tuning of the system, an appreciable reactive loading of the line. A disturbance of the tuning of the terminal side can, upon sacrificing the loading limit of the input side (increase of the load resistance) be compensated by an adjustment in the same sense of the input side tuning. A pure ohmic loading of the link line occurs under the same circumstances if the leakage reactance on the input side is compensated by a series condenser. A detuning on the terminal side can in this case be completely compensated by a readjustment of the tuning in the opposite sense of the input side without affecting the load conditions. The possibility of a mutal exchange of capacity leaves a large margin for the tuning, so that the latter is well below critical.

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SOME RECENT DEVELOPMENTS IN PHYSICAL RESEARCH ON ATOM NUCLEI.

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Among all scientific achievements accomplished during these last years, research work carried out on artificial atom-transmutation may well stand in the first place. A new branch of physics appears to be in rapid development. Physicists are at present not only able, by way of reliable experiments, to transmute known chemical elements, but also to produce artificially a large number of new, previously unknown sorts of atoms. Among these elements especially the 300 artificially radioactive kinds of atoms are of great interest. The high velocity atomic nuclei required for artificial atomic transmutations are produced in the most satisfactory way with the help of the cyclotron. Artificial radioactivity is of greatest importance for chemistry and especially for investigation of biological processes. The huge energies set free by way of atomic transmutations appear to contain undreamed-of possibilities for technical application.

I. NUCLEAR CONSTITUENTS AND ENERGIES.

PHYSICISTS are to-day of the opinion, that all the happenings of Nature may be accounted for by field-transmitted interactions of a few simple *elementary units of matter*. These elementary particles to which, according to wave mechanics, we must ascribe at the same time corpuscular and wave nature, we divide into light and heavy particles.

Above all, electrons belong to the group of *light elementary particles*. They occur as negatively charged negatrons $-\varepsilon$, as well as positively charged positrons $+\varepsilon$. The mass of an electron expressed in atomic units, is equal to $0 \cdot 000543$. (The mass of oxygen has been arbitrarily assumed as $= 16 \cdot 000$.) The electron is, therefore, about 2000 times as light as a hydrogen atom. There also exist the so-called *mesons*, or heavy electrons. They carry the same charge, but are about 160 times heavier than electrons. Among light particles we also find light-quantas or *photons*, which serve as energy transmitters in all kinds of electro-magnetic radiation, as γ-rays, X-rays, ultra-violet, visible and ultra-red radiations. We may also mention the last known light particle, the hypothetic *neutrino*, the existence of which can be only assumed as a result of experiments, but which cannot as yet be made directly visible. Photons and neutrini carry no charge, and have rest mass zero, which means that they exist only in movement and that their mass depends simply on their kinetic energy, (respectively on their momentum).

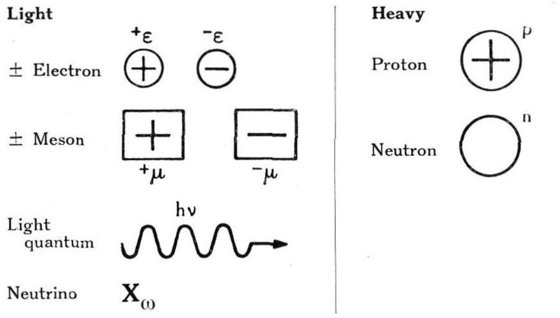

Fig. 1. — Elementary particles.

We also know two *heavy elementary particles*, namely the *proton* p and the *neutron* n. The proton carries the same positive charge as the positive electron, while the neutron carries no charge. The mass of both particles is about 1, expressed in atomic units, in other words they are nearly as heavy as a hydrogen atom. All these elementary particles possess a spin, which, exactly like their mass or their charge for example is characteristic of the particle. This spin is quantized and is a multiple of a natural unit.

$$\left(\frac{h}{4\pi} = \frac{\text{Planck constant}}{4\pi}\right).$$

These fundamental units of matter should not be imagined as undestroyable, invariable particles, the quantity of which is always constant in Nature: there are many different *transmutation processes* which take place among these elements. In the case of *pair creation* or *"materialization of light"*, an un-

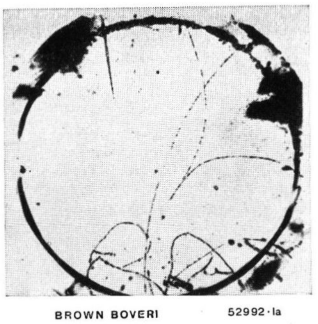

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Fig. 2. — Photograph of pair creation: an electron pair is created in a Wilson cloud chamber. The positive and negative electrons show two tracks curved in opposite direction in the magnetic field, starting at the generating point.

charged photon (e. g. a light-quanta of γ-radiation which disappears in the process) changes into an electron pair $+\varepsilon$ and $-\varepsilon$. Conservation laws of electric charges and of "mass + energy" apply to these transmutation processes, that is, a + and a — electron appear simultaneously and the energy of the light-quanta reappears in the mass and in the kinetic energy of the thus formed electron pair. We have here a proof of the equivalence of energy and mass, these being but different names given to the same natural quantity. Because of this, there exists a fixed conversion factor between mass and energy:

$$\text{Mass} = \frac{\text{energy}}{(\text{velocity of light})^2}$$

The process just the reverse of pair creation is known as *"annihilation of matter"* or *pair-annihilation,* in which a + and a — electron transform generally into two light-quantas, the electron charge vanishing completely. This pair-annihilation is the cause of the only temporary existence of positive electrons: they always encounter negative electrons in matter and decay. In a similar way a meson can spontaneously transmute into an ordinary electron and a neutrino, as in a radioactive process. This process can often be observed in cosmic radiation, where mesons appear free.

There are also transmutations between the two heavy particles — the proton and the neutron. These are the so-called β processes, causing the β-radiations of the radioactive elements: a neutron transmutes spontaneously into a proton, a negative electron and a neutrino being radiated. The mass of a neutron is 1·00895, and it is sufficient to cover those of the proton and electron obtained (respectively 0·00759 and 0·00054). There remains even a surplus of mass which serves as kinetic energy for the electron and the neutrino. A proton can also, if energy is added, transmute into a neutron and a positive electron.

We know for certain, since Rutherford's classic researches, that the atom is a *„nuclear atom"*. It is composed of a small, heavy and positively charged *nucleus* surrounded by an extensive *core* containing light negative electrons only. The nucleus contains only heavy elementary particles, protons and neutrons and possesses no electrons. The fact that the atomic weight of proton and neutron is almost exactly 1 explains why the atomic weights of the various kinds of atoms are expressed by almost round numbers. The quantity z of protons, determining the charge of the nucleus, equals the atomic number of the element in the periodic system. This *positive nuclear charge,* therefore, determines absolutely the *chemical properties* of the atom, for it determines the quantity and arrangement of the negative electrons in the atomic space, where all the chemical processes take place. The number of neutrons in the nucleus is roughly equal to the number of protons. For heavier nuclei only there are slightly more neutrons present than protons. In order to allow a direct reading of the number of protons and neutrons in a nucleus, the quantity of protons is given by an index located to the lower left of the chemical symbol whereas the rough atomic weight (number of protons and number of neutrons) is indicated by an index at the upper right of the symbol. $_8O^{16}$, for instance, is an oxygen atom nucleus with 8 protons and 8 neutrons, thus having a gross atomic weight of 16.

Positive nuclear protons repulse each other, according to Coulomb's law, very strongly in the small distance of about $3 \cdot 10^{-13}$ cm. which they have at their disposal in the nucleus. This repulsion attains about 20 kg weight per proton for a medium atomic weight, a huge force for such a small particle. Because of this repulsion, a nucleus would fly apart were there not strong attractive forces between the constituents of the nucleus. We know, in fact, to-day, of the existence of an extremely high but short-ranged attractive force between the elementary particles, this force having nothing to do with Coulomb's electric interaction. The theory of nuclear forces is being studied especially intensively at present. It is most probable that they are a kind of exchange forces. Such short-ranged exchange forces, which cannot be understood on the basis of the classical particle picture, come out as a result of a consistent application of the quantum theory of fields. Attraction between proton and neutron, for instance, is probably due to the fact that a proton charge goes rapidly over to a neutron, the proton becoming thus a neutron and vice versa. In a similar though more complicated way there also exists attraction between proton and proton, as well as between neutron and neutron. Coulomb's electrical repulsion of protons is simply

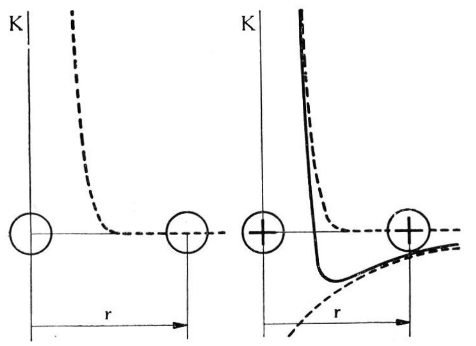


Fig. 3. — Nuclear forces: in the case of two neutrons, there exists only an attractive force at a short distance r. By proton-proton interaction this short range force is superimposed on the slowly (as $\frac{1}{r^2}$) decreasing electric repulsion.

superimposed on this attraction. Similar exchange forces have also their part in chemical combinations; the high attraction of two hydrogen atoms in a hydrogen molecule is quantitatively explained by rapid exchange of the two orbital electrons.

In building up an atomic nucleus with protons and neutrons, a considerable amount of energy is set free because of this strong attractive forces between the constituent elements; the same energy would have to be employed to tear apart the nucleus into its constituent parts.

To simplify matters, an atomic nucleus may be represented as a charge-carrying *liquid drop.* In the same way as in an ordinary liquid drop, where molecules are held together because of their mutual attraction forces (Van der Waal's forces) protons and neutrons are bound together by their mutual attraction. Energy is set free in the form of heat condensation if a water-molecule is added to a drop of water.

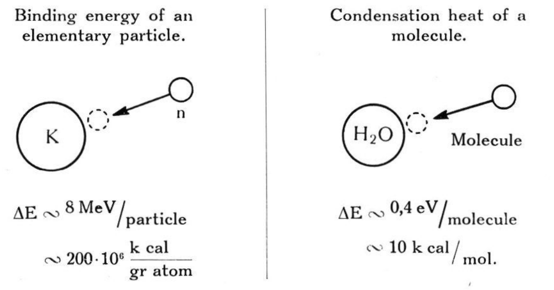
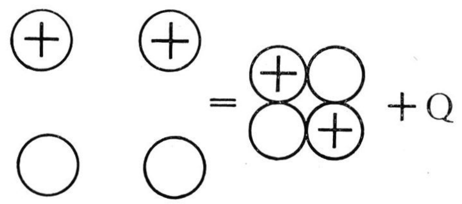


Fig. 4. — Liquid drop model of a nucleus.

On the other hand, in order to evaporate a molecule out of a drop of water, the same amount of heat has to be applied. This energy is 0·4 eV per water molecule.[1] Similarly, considerable energy is set free as "condensation heat", because of the short-range nuclear force, when adding a neutron or a proton to an atomic nucleus. The energy set free in this case is however much larger than in the case of a water molecule, namely about 8 MeV. It is often radiated from the nucleus by way of γ-rays, but it may also happen that a nucleus is subject, after addition of a proton or a neutron, to other radioactive transmutations, setting free the binding energy.



$$\left.\begin{array}{l}2\times1{\cdot}00759\\2\times1{\cdot}00895\end{array}\right\} = 4{\cdot}00277 + \underset{\displaystyle 28{\cdot}2\ \text{MeV}}{\underset{\|}{0{\cdot}03031}}$$

$$\overline{4{\cdot}03308}$$

Fig. 5. — Energy gain with the building up of a helium-nucleus with protons and neutrons: a helium-nucleus is composed of two protons and two neutrons.

The mass of these four elements is 4·03308, helium-nucleus weighing but 4·00277 atomic units, 0·0303 units have thus disappeared in the building up of the nucleus in the form of energy, corresponding to a binding energy of 28·2 MeV per helium-nucleus.

These quantities of energy set free in building up the nucleus are high enough to attain weighable values and appear as so-called "mass defects": the

[1] Electronvolt, eV, is always used as energy unit in physics. 1eV represents the energy taken up by an electron if it falls through a potential difference of 1 volt $1\text{eV} = 1{\cdot}6\times10^{-19}$ Coulomb. 1 volt $= 1{\cdot}6\times10^{-19}$ Joule $= 1{\cdot}6\times10^{-12}$ erg. . . 10^6 eV = 1 MeV.

nucleus weighs less than its constituents. Part of the mass is lost as energy during this combining operation. Thus, for instance, 4·03308 atomic weight units represent the weight of 4 elements, 2 protons and 2 neutrons, composing the helium nucleus, while the helium nucleus itself weighs only 4·00277 units. The mass excess, about $30 \cdot 3 \frac{\text{mg}}{\text{Mol He}}$, has therefore been radiated as energy during the nuclear formation. This energy set free corresponds, according to the equivalence of energy and mass, to 28 millions eV per nucleus, or to 600,000,000 kcal per 4 gr of helium. If we work out, on the basis of the liquid trop model, these binding energies for different nuclei, considering only short-range attraction and Coulomb's repulsion, we obtain a fair agreement between calculated and measured mass defects.

We can now imagine nuclei composed of any number of protons and neutrons and speculate whether these nuclei occur in nature. As a matter of fact, only about *285 stable nuclei* are found, from the lightest element, hydrogen, to the heaviest, uranium. *Most of the atoms we can build up are unstable:* they change over into stable atoms of less energy. The principle of equilibrium applies here as well as in ordinary statics, namely, that the *state of equilibrium* is the *state of lowest energy.*

Principle: energy = minimum.

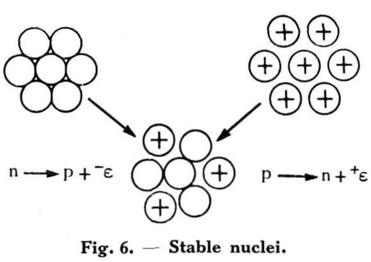
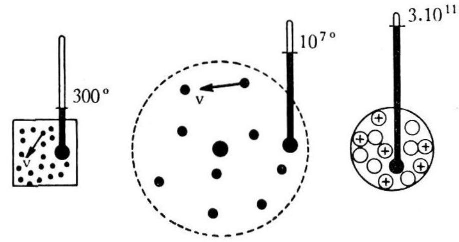


Fig. 6. — Stable nuclei.

A nucleus composed of seven neutrons is unstable; it can, for example, go over into a lower energy level in that some of the neutrons present change into protons. Just so, a nucleus composed only of protons would be unstable; it would go over into a stable level ($_3Li^7$) by means of the transformation of some protons into neutrons.

Consider for instance a nucleus composed of seven neutrons, this corpuscular assembly holds fast together on account of the strong attractive forces between neutrons. There exists, nevertheless, a lower energetic state to which this atom will transform: some neutrons will transmute into protons, negative electrons being radiated and energy set free. Such a nucleus, composed of neutrons only, would become a stable lithium atom $_3Li^7$, composed of three protons and four neutrons. Only three neutrons transmute into protons because the nucleus energy would increase again on account of the increase in Coulomb energy if all the neutrons were to transform into protons. Hence a nucleus which would consist of protons only could not be stable. It also could be transformed into a $_3Li^7$-atom while giving up energy if four protons, emitting positive electrons, change over to neutrons. This proton-neutron transformation demands to be sure some energy, but this will be taken from the Coulomb energy store which diminishes with decreasing charge. Nuclear density too, will somewhat increase with the decrease of the Coulomb repulsion.

In addition to the potential energy due to the forces the nucleus particles have also a very high *kinetic energy.* This kinetic energy of the nuclear neutrons and protons is very great, as it is also for the core electrons, the movement of which is governed by the laws of quantum mechanics. This kinetic energy may be represented by the so-called *"temperature of degeneracy".* Molecular translatory energy of a drop of water at a room temperature, would be $\simeq 10^{-14}$ erg,



	Gas	Electron core	nucleus
$\frac{mv^2}{2}$	$= 6\times10^{-14}\ \frac{\text{erg}}{\text{atom}}$	$= 3\times10^{-9}\ \frac{\text{erg}}{\text{electr.}}$	$= 6\times10^{-5}\ \frac{\text{erg}}{\text{particle}}$
	$= \frac{1}{30}$ eV	$= 2\times10^{3}$ eV	$= 4\times10^{7}$ eV
	$\sim 300°$ abs	$\sim 1{\cdot}5\times10^{7°}$ abs	$\sim 3\times10^{11°}$ abs

Fig. 7. — Atomic energies.

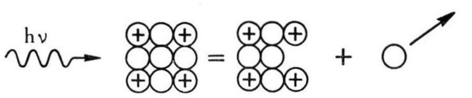
Kinetic energies of elementary particles may be characterized by an "apparent temperature". Electrons move as violently in the atom-core, as if they were a classical gas at 10^{7}° C. Nuclear constituents move so violently that one would find the same kinetic energy only in a gas at 11^{11}° C.

corresponding to an absolute temperature of 300^0. The average energy of an orbital electron is about 10^{-9} erg, corresponding to an apparent temperature of $10^{7\,0}$ abs. The translation energy of a nucleur particle is about 10^{-5} erg, corresponding to an apparent temperature of $10^{11\,0}$ abs. This huge "temperature of degeneracy" explains the fact that it is impossible to influence nuclei with the temperatures which we have at our disposal.

II. NUCLEAR TRANSMUTATION.

a) A nuclear transmutation can, in principle, be obtained simply through *addition of energy*. Exactly as one can evaporate a few water molecules by heating a drop of water, so can one bring neutrons or protons to "evaporation" by addition of energy to the nucleus. The latter must be, of course, considerably higher in case of a nucleus. For instance, a neutron

Nuclear transmutation with γ-radiation.



γ - Quant + ${}_4Be^9 = {}_4Be^8 + {}_0n^1$
${}_4Be^8 = 2 \times {}_2He^4$

Fig. 8. — Nuclear photo-electric effect.
A light-quantum having sufficient energy will separate a neutron from a beryllium-nucleus.

can be evaporated if a beryllium-atom is exposed to γ-radiation of radium, as follows:

$$ {}_4Be^9 + \gamma \cdot \text{energy} = {}_4Be^8 + {}_0n^1 $$
$$ {}_4Be^8 = 2\, {}_2He^4 $$

The beryllium-nucleus, with an atomic weight of 9, changes thus over to an isotopic beryllium-nucleus, with an atomic weight of 8, and one neutron. Beryllium 8 is unstable and splits into two helium-atoms. This so-called "nuclear photo effect" has been observed on very many atoms. Natural γ-rays are, unfortunately, not very energetic (2·62 MeV max.), but it is now possible to produce γ-rays with very high energies up to 17 MeV by means of nucleus reactions, which are much more appropriate for these processes.

b) Another nuclear reaction is the mere *addition of a neutron* to a given stable atom. Thus, for instance, it is possible to produce a so-called "heavy hydrogen" atom or deuteron, having an atomic weight of 2, out of a light hydrogen atom by the following formula:

$$ {}_1H^1 + {}_0n^1 = {}_1D^2 + \text{energy}. $$

Such a binding sets free the energy in form of photons (γ-rays).

c) Addition of a neutron to an existing nucleus often brings forth so-called *exchange effects:* the adding of a slow neutron produces an intermediate unstable nucleus which splits immediately into two. Examples of this process are:

$$ {}_5B^{10} + {}_0n^1 = {}_5B^{11} = {}_3Li^7 + {}_2He^4 $$
$$ {}_7N^{14} + {}_0n^1 = {}_7N^{15} = {}_6C^{14} + {}_1H^1 $$

(In the first example, the neutron is exchanged with a He-nucleus, and in the second with a proton.) The intermediate nuclei are not the ordinary boron and nitrogen-nuclei which may also be stable, but are "excited nuclei" which have received surplus energy through the neutron incorporation. Such an excited nucleus may be compared to an overheated drop of water. Just as such a drop will suddenly partly evaporate, the excited nucleus will emit a particle. It can also go over to its ground state by radiation of γ-quantas, but this is rarer.

d) It is, of course, possible to disintegrate in many different ways every atom by bombarding it with *fast neutrons*. The energy of the bombarding neutrons "heats" the nucleus so much that it will partly "evaporate". There are (n, 2n) or (n, 3n) reactions by which a fast neutron may be shot in and thus bring about the evaporation of two or three other neutrons. Many (n, p), (n, d) and (n, He) reactions are also known; these are processes by which a neutron is shot into a nucleus, the latter being exchanged for a proton (p), a deuteron (d) or a helium particle (He). According to the nucleus concerned, the energy relationships are of course quite different.

Examples:

(n, 2n) . . . . ${}_{29}Cu^{63} + {}_0n^1 = {}_{29}Cu^{62} + 2{}_0n^1$
(n, 3n) . . . . ${}_9F^{19} + {}_0n^1 = {}_9F^{17} + 3{}_0n^1$
(n, p) . . . . ${}_{26}Fe^{56} + {}_0n^1 = {}_{25}Mn^{56} + {}_1p^1$
(n, He) . . . . ${}_{27}Co^{59} + {}_0n^1 = {}_{25}Mn^{56} + {}_2He^4$

These nuclear-transmutations with fast or slow neutrons are, in principle, the most simple. The neutron which approaches a nucleus is submitted to no force until it reaches the immediate neighbourhood of it. Only then will it be seized by the above mentioned nuclear force and fall into the nucleus.

Neutrons are however not at the immediate disposal of the physicists, because they don't exist freely in Nature. Free neutrons have but a short life in matter, as they are rapidly absorbed by atomic nuclei.

e) The physicist must proceed from natural stable atoms to get his nuclear transmutation processes. He has to bring them in contact so that they may react and exchange their elements.

Atomic nuclei repulse each other strongly because of their positive charge; to overcome this, nuclei must possess high kinetic energies. No other means is unfortunately known to-day to bring the nuclei in contact than the primitive *bombardement of resting atomic-nuclei* with very fast moving other atomic-nuclei. The use of these ultra rapid particles has led to the notion of *"atom-smashing"*, although such reaction may also happen if two nuclei are brought close to each other with no speed. It is thus better to speak of nuclear reactions than of atom-smashing.

The first nuclear reaction of this kind was achieved by Rutherford: he used the high speed $_2He^4$-nuclei, radiated as α-rays by RaC′ and possessing an energy of 7·83 MeV[1] to bombard nitrogen, and he observed the following nuclear reactions:

$$_7N^{14} + {}_2He^4 = {}_8O^{17} + {}_1H^1.$$

It is possible to obtain nuclear reactions by means of α-radiation, with very many light elements. The Wilson cloud chamber has rendered invaluable services

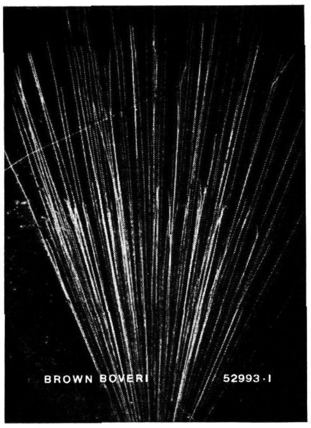


Fig. 9. — Wilson chamber photograph representing artificial transmutation of atoms.

An α-particle strikes a nitrogen nucleus with which it reacts. An oxygen and a hydrogen nucleus are produced, trajectories of which are visible.

in researches on such processes, for it permits the visualization of trajectories of nuclei associated with the reaction and the measurement of the energies and momentum of the particles. If high speed nuclei necessary for nuclear reaction are to be *artificially* produced, one must have devices in which atomic nuclei are accelerated by means of high voltages. A great number of plants have been built in recent years which can produce a d.-c. voltage of several million volts by means of transformers and rectifiers or by means of the electrostatic principle with high speed running belts. Particle rays, of which every single particle possesses an energy of several millions of eV, are produced with an electron gun. The voltage of such devices is actually limited to about 4 million volts.

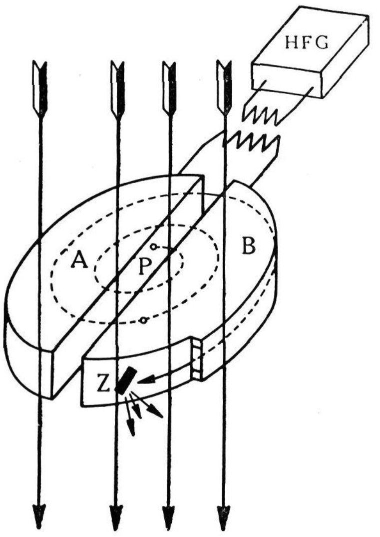


Fig. 10. — Principle of the cyclotron.

A and B are the two halves of a metallic box; P is the source of protons; the dotted spiral represents the path of a proton. Z is the target-substance bombarded by the particles which disintegrate its atoms. HFG is the high-frequency generator.

A more elegant and efficient high velocity generator is the cyclotron: this device accelerates the same atom repeatedly. The particle moving at constantly increasing speed must be guided back in proper synchronism into the accelerating alternating field. This constraining of the particles to move in circular paths is achieved with a strong magnetic field.

A circular vacuum chamber with a diameter of about 1 m and a height of 25 cm, is located between the poles of a large electromagnet. This chamber contains two accelerating electrodes or dees which can be compared to the sections of a pillbox divided in two equal parts by cutting along a diameter. These two dees are insulated from the wall as well as from each other and a high-frequency voltage is applied so that an alternating voltage of about 50,000 volts is acting between them. An ion source is located in the middle of the chamber which produces atomic nuclei, for instance protons or deuterons. The ions enter the electric field, move back and forth under its influence and then begin to travel along a spiral path between the dees. A freshly created ion will, for instance, be accelerated into the interior of the right dee if at the moment it has a negative and the left dee a positive charge. Within the space free from electric field the interior of the dee, the ion cannot travel along a straight path, but will be compelled by the Lorenz

[1] The velocity of such a He-nucleus is about $^1/_{15}$ of the velocity of light, that is 20,000 km/s = 72,000,000 km/h.

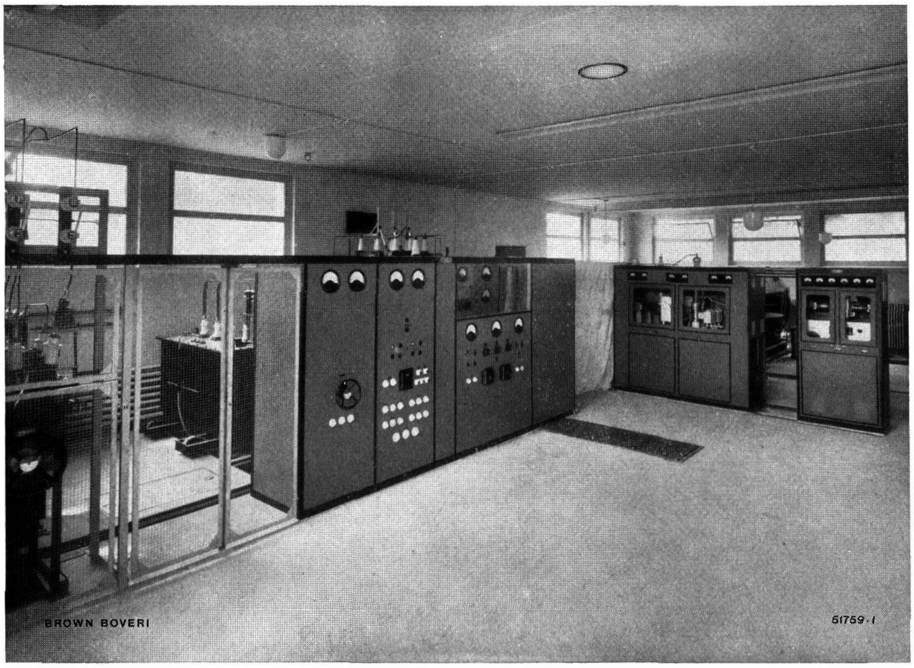


Fig. 11. — General view of the cyclotron set-up.

Left: Power-plant and 15 kV mutator feeding the h. f. output stage.
Centre: Max. 50 kW h. f. output stage cabinets.
Right: H. f. preliminary stages. Part of the magnet can be seen between the cabinets.

force into a circular path. After a certain time it re-enters the gap between the dees. The polarity of the dees having, however, just in this time reversed, the ion will be accelerated into the left dee. The radius of curvature of the path will be increased in the same proportion as the velocity, and the ion will re-enter the gap at the very moment of the next polarity change (Larmor's Theorem). Because of the extremely short time of such a circular travel, namely $^1/_{30,000,000}$ sec., determined by the magnetic field intensity, the alternative voltage polarity has to change over 30,000,000 times per second, in other terms high-frequency voltage must be applied. Furthermore, in order to obtain a high velocity increase, the voltage must be high. As may well be seen, a velocity of 30,000 km/sec., that is $^1/_{10}$ of the velocity of light, corresponds to an angular velocity of 15,000,000 rev/sec. along a circumference having a radius of 50 cm.

The Federal Institute of Technology in Zurich possesses a cyclotron, which can accelerate deuterons to 14 MeV and α-particles to 24 MeV. The magnet constructed by the Oerlikon Machine Works weighs 40 tons. The diameter of the pole pieces is 90 cm, the field intensity, with an air-gap of 15 cm, being 18,000 A/cm. The excitation power of the magnet amounts to 200 kW.

The *high-frequency part of the cyclotron* was built by Brown Boveri. It is a short-wave generator having an output of 50 kW with a wave-length of 20 m. Electric oscillations are produced in a preliminary stage, their frequency being maintained at great constancy by appropriate means. These oscillations are amplified and their frequency is twice doubled in two further stages, the necessary control output of about 1 kW thus being fed into the final stage.

This stage contains two dismountable Brown Boveri power-tubes. These are water-cooled triodes connected to a molecular pump and operating as class-C push-pull amplifiers.

The cyclotron-chamber has been developed at the Physical Institute of the Federal Institute of Techno-

Fig. 12. — H. f. preliminary stages (right) and output stage (left). In the left-hand cabinet, a dismountable Brown Boveri transmitting tube can be seen, as well as parts of the anode oscillating circuit.

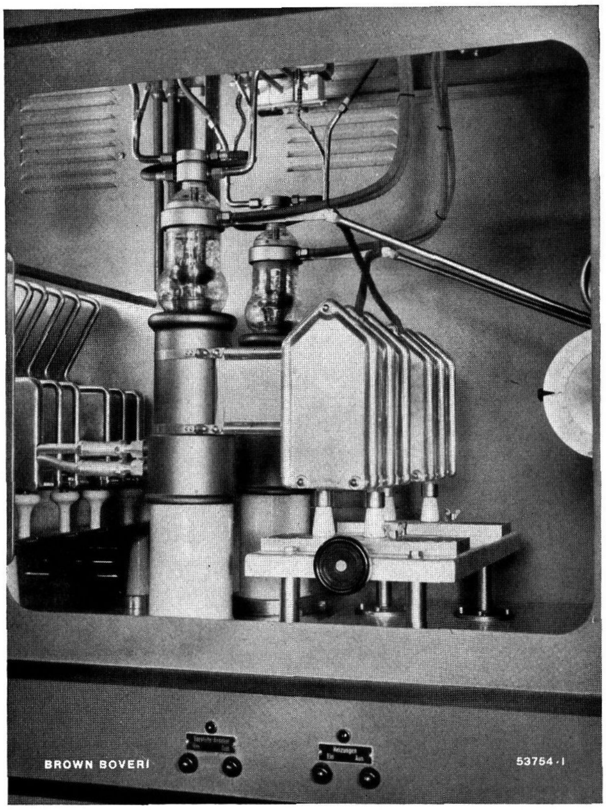


Fig. 13. — Right: demountable, water-cooled Brown Boveri tubes, with neutralizing condensers; left: anode oscillating circuit condenser.

The tubes are constantly connected by means of an insulating cylinder to a high vacuum pump, located in the cabinet.

logy in Zurich and shows important modifications in comparison with some already known constructions. The high-frequency part of the chamber together with the accelerating dees DD, has been built up as shortened Lecher system having an effective wave-length of $\frac{\lambda}{2}$.

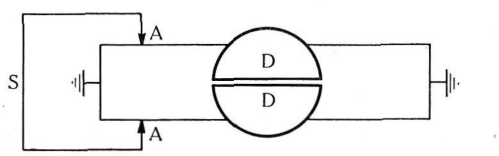


Fig. 14. — Atom accelerating device.

The two box-halves, in which atoms are accelerated, are connected in the centre of a Lecher system oscillating on the half-wave. Alternative h. f. voltage is applied at AA.

This arrangement has a number of advantages:

1. Symmetrical voltage repartition along the accelerating gap.
2. Possibility of a strong fixation of electrodes, without using isolators (both ends of the system having earth-potential).
3. Possibility of exact adjustment of the system to the energy input.
4. The high-frequency is applied at a point where the Lecher system voltage is about 25 times lower than at the deflecting electrodes; thus the Lecher system acts as a transformer for the deflecting voltage. The ions are produced in a small gas-chamber by means of a low-voltage arc. The vacuum of the whole accelerating-chamber is produced by means of an automatic oil-diffusing pump of 1000 l/s suction power, built at the Institute.

The biggest cyclotron built so far (in Berkeley, California) has a 400-ton magnet with pole pieces having a diameter of 2·5 m. High-velocity deuterons of 16 MeV and He-nuclei of 32 MeV have been produced by this apparatus. The cyclotron is used especially as a powerful neutron-source and can produce artificial radioactive substances. The nuclear reaction ${}_3Li^7 + {}_1D^2 = 2\,{}_2He^4 + {}_0n^1$ gives a very good yield of neutrons and is most generally used to produce neutrons. A still more powerful cyclotron with a 4000-ton magnet has been planned chiefly for biological and medical research and will be operating in Berkeley in about 3—4 years.

Until now, many kinds of nuclear reactions have been carried out and energy-yields have been measured, and a considerable number of new, previously unknown kinds of atoms have been produced.

III. ARTIFICIALLY RADIOACTIVE SUBSTANCES.

Among these artificially obtained atoms, *artificially radioactive atoms,* of which more than 300 sorts are known to-day, are of chief interest. Many atoms created by a nuclear reaction are unstable and decay, by way of the above mentioned transformation of a proton into a neutron or vice versa into stabler elements, with an emission of positive or negative electrons, also frequently γ-rays. Of great interest to the physicist is the fact that it is possible to produce natural radioactive substances, such as radium-E (β-radiation) and polonium (α-radiation) by means of the non radioactive bismuth.

As an example of an artificially produced radioactive substance, we may mention radioactive sodium having an atomic weight of 24, whereas the weight of the known stable sodium is 23. This Na^{24} can be obtained by means of many transmutation processes, for instance by means of addition or exchange of neutrons:

$$_{11}Na^{23} + _0n^1 = _{11}Na^{24} + \text{photon}$$
$$_{12}Mg^{24} + _0n^1 = _{11}Na^{24} + _1H^1$$
$$_{13}Al^{27} + _0n^1 = _{11}Na^{24} + _2He^4$$

or by means of deuterons:

$$_{11}Na^{23} + _1d^2 = _{11}Na^{24} + _1p^1$$
$$_{12}Mg^{25} + _1d^2 = _{11}Na^{24} + _2He^4 \text{ etc.}$$

Radioactive $_{11}Na^{24}$ decays as β-radiation, as follows:

$$_{11}Na^{24} = _{12}Mg^{24} + -\varepsilon + \text{energy.}$$

The emitted electrons have an energy of max. 1·4 MeV, and γ-radiation can also be observed. The mean life time is about 14·8 hours, that means half of the atoms are disintegrated after 15 hours, a quarter only of radioactive atoms remains after twice 15 hours, etc.

These artificially radioactive elements are to play a most important part in chemistry and especially in biology and medicine. No other discovery since that of the microscope has been so important for the biology of metabolism and for pharmaceutical chemistry as that of artificial radioactivity.

The applicability of radioactive atoms to chemistry and biology is due to the fact that a radioactive element *does not differ in any way*, chemically or physiologically, from its stable isotope, as long as the action of radioactive radiation can be disregarded. Radioactive sodium acts exactly as ordinary sodium. Atoms of radioactive elements are however *characterized by their radioactivity;* they are, so to say, labelled, and can thus be recognized at any time among the chemically equivalent but stable atoms. It is clear that radioactive measurements can easily identify the presence of smaller amounts of radioactive phosphorus introduced as NaH_2PO_4 in any tissue. The presence of existing phosphorus in the tissue does not hinder these measurements, as the new phosphorus introduced will be distinguished immediately by means of its radioactivity.

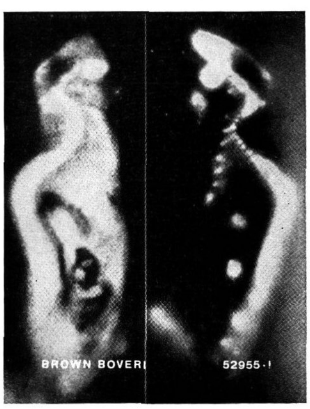


Fig. 15. — Autoradiogram showing deposits in a rat of (left) radioactive phosphorus and (right) of radioactive strontium.

Radioactive substances have photographed themselves by means of their radiation. Note the more uniform repartition of phosphorus in the bones and the tissues, while strontium deposits more selectively in bones.

One of the most striking examples of the use of these "labelled" atoms is that of radioactive carbon in the *investigation of the assimilation process in green plants.* By means of the radioactive method, which is about a million times as sensitive as the chemical method, it has been possible to depose the classic theory of assimilation. This classic theory assumes that CO_2 is only absorbed by plants when they are under light and that it is reduced to formaldehyde and oxygen:

$CO_2 + H_2O + \text{light} = CH_2O + O_2$. By means of carbon dioxide where carbon is replaced by radioactive carbon, it can be easily proved that plants absorb carbon dioxide even in *darkness;* radioactive carbon of the dioxide is found quantitatively again in the carboxylic acid group $R{-}C{=}O$ where R is a radical of roughly
$\diagdown OH$
the atomic weight of 1000. This acid is reduced, under delivery of oxygen, to an alcool group:

$$R - COOH + H_2O + \text{light} = RC = H_2 + O_2$$
$$\diagdown OH$$

through the action of light in the presence of chlorophyll. It can be shown, by means of radioactive measurements, that 20 % of carbon dioxide absorbed by barley, for instance, is transformed into sugar after two hours. It is clear that such researches could never have been accomplished without the help of radioactive carbon, for it would have been impossible to distinguish the C atoms being formed from those C atoms already contained in the plant.

Radioactive elements are also of very great importance for all researches concerning metabolism in the human body. It is now possible to pursue easily the absorption, transport and transformation of all kinds of drugs when the latter contain radioactive labelled elements. Because of the high sensitivity of such indicators as the Geiger counter, it is sufficient to make the organism absorb only very small quantities of such radioactive substances. It is even possible to proceed with investigations on intact bodies, since the γ-rays of radioactive substances radiate from the body because of their high penetrating power, and may be measured by the Geiger counter. As an example, *we may mention absorption and transformation of* *iodine by the thyroid gland.* It is known, that the iodic concentration is extremely small in all the tissues of the human body with the exception of the thyroid gland, where it is 10,000 times as high as elsewhere; here iodine is transformed into thyroxine, an organic iode-combination which regulates the speed of oxydation in the body. In case of lack of thyroxine, oxygen absorption by the body becomes reduced and the whole meta bolism will slow down. If thyroxine is too abundant, oxygen absorption and assimilation is increased. If a few milligrams of caliumiodide with radioactive iodine are injected into the body, it is possible to verify its arrival in the thyroid gland a few minutes later with a Geiger counter located near the throat. Iodine saturation of the thyroid is attained in one or two days on normal individuals: about 4% of the absorbed iodine is found in the thyroid gland, whereas the rest has been in a greater part eliminated by the organism. Individuals suffering from the Basedow desease, have the thyroid gland working too actively and the absorption of iodine is very much increased. Their thyroid absorbs 12—15% of the radioactive iodine in a few hours; the latter, rapidly transformed into thyroxine, is then led back into the blood-system where it accounts for an acceleration of the metabolism. Individuals with a subnormal thyroid gland absorb very little iodine.

Absorption of radioactive substances in the human body can also be often *extremely selective;* radioactive strontium will, for instance, deposit nearly exclusively in *bones.* There exists therefore a possibility of a selective radio-therapeutical treatment of certain organs, without hurting other, but there have as yet been too few experimental results in that direction. Very interesting results of plant absorption of phosphorus have already been obtained, as well as others of the very complicated gradual absorption of radioactive iron into blood haemoglobine.

Radioactive substances, such as radioactive sodium, which have been prepared in very strong and active compositions, have naturally a great importance already for *therapeutic* purposes.

Radioactive metals are utilized in *metallurgy* to investigate phenomena of mixture, self-diffusion and precipitation.

Unfortunately it is not yet possible to transmute weighable quantities of an element; very small quantities only have been transmuted so far, which can be chemically determined. This is not regretted by physicists, as Nature offers to the technician an abundance of substances or substitutes. It is however very regrettable that the huge *energy yields* of nuclear reactions cannot be technically utilized, as there is no substitute for energy. This energy yield is especially large for the decay of the uranium nucleus. Uranium is the last element in the periodic system and the $_{92}U^{235}$ uranium-nucleus is composed of 92 protons and 143 neutrons. It is easy to see on the basis of the liquid drop model, that this nucleus lies very near the limit of stability and that the Coulomb's electrical repulsions are, because of its high charge, nearly superior to the attraction forces. In fact, addition of a slow neutron to the nucleus suffices to provoke the formation of an *unstable nucleus of 235-uranium:* after this neutron addition, the nucleus decays into two smaller nuclei. This disintegration has to be imagined as if the unstable nucleus were to vibrate and split in two; at the same time, two or three neutrons will also "evaporate". The two smaller nuclei created will be separated by the high Coulomb's repulsion and thus get huge kinetic energies: the energy set free through disintegration of an uranium-atom equals nearly 160 MeV. If one kilogram of uranium could be disintegrated in that way, about 16 billions of k/calories would be set free, corresponding to a coal-combustion of 2 million kilograms.

Physicists naturally search assiduously for a means to render such energies useful. First of all, only one of the three uranium-isotopes decay in the above manner: uranium is composed of three sorts of atoms of the atomic weights: 238, 235 and 234. Uranium 235, which disintegrates so easily, forms but about 0·7% of the total composition. To-day, efforts are being made to increase the 235 percentage by means of new methods of isotopic separation. If the U 235 were obtained, it would be necessary to disintegrate the atoms in a chain reaction, that is, neutrons obtained through atomic disintegration should immediately cause further disintegration, so that the reaction started may proceed automatically through the whole mass of uranium. It is already known to-day that only slow neutrons can operate uranium-disintegration; it is therefore almost certain that the reaction started would slow down because of the increasing velocities of neutrons produced by high temperatures which are obtained. This circumstance is duly appreciated because no explosion can thus happen during the uranium-disintegration and energy is set free slowly just as in coal-combustion.

It is known with certitude to-day that processes of nucleus transformations are the formidable *energy-suppliers of the stars.* Stars radiate energies many million times as great as chemical reactions could produce. Processes occuring in the case of the sun, for instance, are well known to-day. The sun looses through radiation such enormous quantities of energy that if we assume it to be composed of carbon and oxygen, the combustion of this carbon and oxygen would produce energy during 3000 years only. Hydrogen is transformed into helium, by means of carbon acting as catalyser. The process operates in five stages and develops about 150,000,000 k/calories per gram of transformed hydrogen. (The combustion heat is only 48 k/cal. per gram for hydrogen.) In spite of the enormous temperature of about 20,000,000^0, which reigns in the center of the sun, these atomic reactions fortunately develop very slowly, as only a few nuclei possess the high velocity, sufficient to overcome Coulomb's repulsive forces and to start nuclear reactions.

The sudden explosion of *supernovae*, where stars go over to a new state of equilibrium accompanied by enormous radiation, 60 million times as strong as that of the sun, may be explained by means of nuclear physics.

Researches in the field of artificial nuclear processes progress extremely rapidly, particularly in the United States Institutes, which have at their disposal generous financial means as well as a numerous staff. The science of physics has been, in a short time, greatly enlarged and enriched thanks to the many nuclear problems solved, and our knowledge of the constitution and interaction of elementary particles has benefited greatly. It remains a thrilling, but unfortunately not as yet answerable with certainty question whether this field will not, in a near future, be also made fruitful for technical applications.

(MS 818) *Prof. Dr. P. Scherrer. (E. H.)*

BROADCASTING STATIONS.

Decimal index 621.396.712

AFTER completing a considerable amount of developmental work in connection with the study of high frequency and after constructing various types of transmitters of small and medium power, but especially after design and manufacture of our demountable high-power transmitting valves, which possess considerable technical and economical advantages, we have now taken up the construction of *complete broadcasting stations.*

Brown Boveri is in a position, enjoyed by only a few firms, of being able to supply everything necessary for this purpose, namely the power-supply, audio-frequency and high-frequency parts, from our own workshops and according to our own designs. We had already manufactured important parts for large transmitting stations long before taking up the general manufacture of high-frequency equipment. From 1929 up to the present time, a large number of high-voltage mutators for wireless stations, for voltages up to 21 kV and outputs up to 1500 kW, fitted with the pioneer Brown Boveri short-circuit extinction by grid control, has been put into service by us. In addition, we also supplied filter circuits, current generating sets for cathode heaters, and modulation transformers for home and abroad.

As the first step in manufacturing wireless transmitters, a test transmitter for a carrier output up to 300 kW was set up a year ago in our laboratories. The results obtained were so favourable that the General Management of the P. T. T. (Post, Telegraph, Telephone) in Berne stated their willingness to test out this transmitter in the largest Swiss broadcasting station for the general wireless transmissions. In the early part of 1941 the erection and adjustment of the transmitter on site could be commenced and as early as the middle of July the daily transmission could be taken over. Up to the middle of December 1941, the test transmitter, equipped with our demountable transmitting valves type DT 20/150 for a carrier output of 80 kW, has been on the air for more than 1500 hours, during which time the total interruption time amounted to less than one hour, and was consequently very small. Although the modulation is effected temporarily in the anode circuit of an intermediate stage, it was possible to attain a distortion factor of 3·9 to 4·3 % for an 80 % modulation, and a noise level of — 64 db referred to a 100 % modulation. Moreover a particularly good frequency response was obtained, as may be seen from the following table:—

Frequency response (referred to 1000 cycles).

F in cycles	35	50	100	200	1000	2000	4000	6000	8000	10,000
Variation in db	+ 1·1	+ 0·4	+ 0·1	0	0	+ 0·1	+ 0·3	+ 0·6	+ 1·2	— 1·3

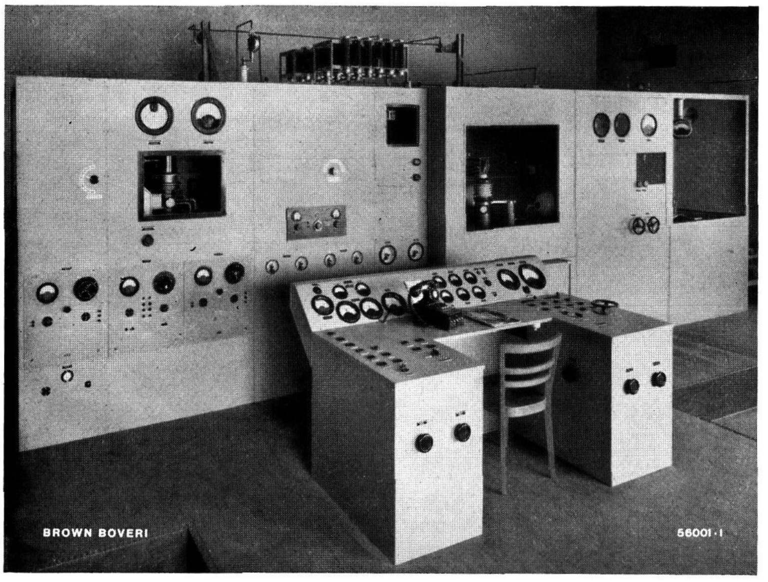


Fig. 1. — Brown Boveri test transmitter for 80 kW carrier output.
In the centre of the plant the panel with the demountable transmitting valves Type DT 20/150 is visible.

Replacement of old sealed-off glass valves by demountable Brown Boveri valves is to be recommended from the point of view of economy as well as on account of the ease with which they may be adjusted, i. e. on account of the facility of matching the valve characteristics for push-pull operation.

Quite apart from this test transmitter we are at present building transmitters of medium power, in exceptional cases up to 150 kW. These are built according to the most modern design employing the so-called "unit" system and are provided with complete automatic control. A circuit has been developed for these transmitters which requires a comparatively small power input. The individual "units" of these transmitters comprise independent stages which can be automatically controlled from a centralized control desk. Transmitters built in this manner are easily transported and can be erected on site and put into operation in the shortest time. We shall give a full report on these stations when the standardization has been completed.

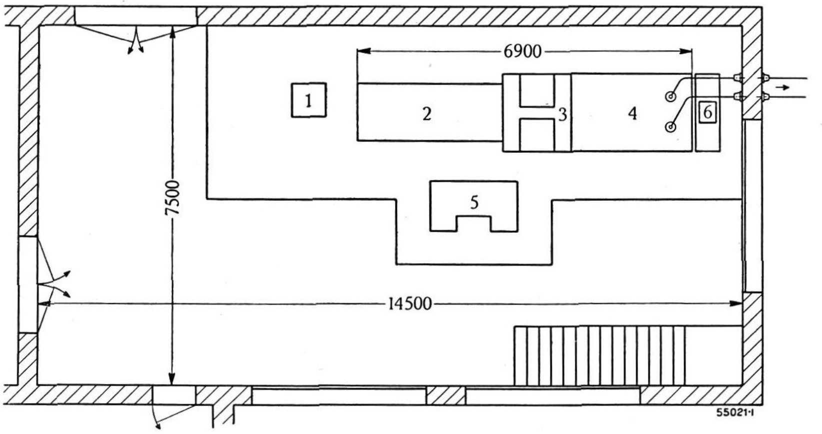


Fig. 2. — Plan of the test transmitter shown in the above illustration.
1. Modulator. 2. First stages. 3. Final-stage valves. 4. Final stage. 5. Control desk. 6. Artificial aerial. 7. To the aerial.

The requirements for frequency stability laid down in the CCIR[1] rules were satisfied and the upper harmonics likewise remained within permissible limits.

The good results obtained with the test transmitter are such that its carrier output may now be raised from 80 kW to 100 kW with the same demountable valves and with a simultaneous improvement of the quality of transmission, an alteration made possible by the design of a large modulator now in process of manufacture. If the international agreements for European broadcasting stations were to permit it, the carrier output of this transmitter could be raised to 150 kW.

The good results previously mentioned have also led to the decision to employ our demountable valves of the same type as in the test transmitter, instead of the well-known triode CAT 14 of the original transmitter, for general broadcasting purposes.

[1] Comité Consultatif International des Radiocommunications.

(MS 821) *F. Schmidlin, E. Aubort. (D. S.)*

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FRONTISPIECES AND SEPARATE ILLUSTRATIONS.