Physics of Our Day

RADIO ELECTRONICS

(On the 100th Birthday of A. S. Popov)

A. M. KUGUSHEV

Usp. Fiz. Nauk **67**, 663-703 (April, 1959)

MARCH 16, 1959 was the 100th birthday of the outstanding Russian physicist, Aleksander Stepanovich Popov (1859 – 1906). Continuing Heinrich Hertz's experimental investigation of electromagnetic waves, on the basis of the work of Maxwell and Faraday, Popov arrived at the invention of wireless telegraphy.

It can be said that the invention of wireless telegraphy gave rise to a new branch of science and engineering, now universally called radio electronics.

Rapid progress has caused radio electronics to become an all-inclusive field, so that a definition of its scientific and technical scope becomes quite difficult.

Only recently, radio engineering was classified as a branch of electrical engineering – dealing with high frequency currents – having but one practical application, radio communication. Modern radio electronics engages in the study and various practical applications of electric oscillations in a very extensive spectrum, from the extreme low frequencies to those corresponding to the millimeter range of electromagnetic waves.

The scientific content of modern radio electronics includes three principal branches: a) study of radiation, transmission, and propagation of radio waves, i.e., electromagnetic waves from several millimeters to hundreds of kilometers long; b) study of the interaction between an electromagnetic field and free electrons or molecules; c) conversion of electric oscillations from one type of signal into another in linear and nonlinear circuits and the passage of electric signals through such circuits.

Many a branch of engineering has resulted from an application of some development in physics. Progress in engineering leads in turn to further advances in physics, by providing the technical means for new experiments and by raising new, more complicated problems. Perhaps no other branch of engineering has contributed more during the past two or three decades to the progress in modern physics than radio electronics. An example is the greatest accomplishment of modern physics, the study of atomic structure and the realization of nuclear reactions. Other examples are radio astronomy and radio spectroscopy. It can be said that radar and microwave engineering have produced these new branches of physics.

The technical means created by radio electronics extend without limit human ability to sense the outside world and subjugate the forces of nature to human interests.

Radio broadcasting, including electroacoustics in all its forms, telegraphic and telephonic radio communication over the entire globe, television and facsimile, radar and radio navigation, radio geodesy and radio meteorology, radio astronomy – the investigation of the universe – and radio spectroscopy – the study of the microcosmos, electronic automation and high-speed computing machines which facilitate not only physical but also mental human labor, accelerators for atomic particles and the control of nuclear reactions, radio geology – the investigation of the mineral resources of the earth – and high-frequency heating in technological processes, investigation of biological processes and the use of electronics in medicine – this is a far from complete listing of the great variety of scientific and practical applications of modern radio electronics.

Many modern technological processes would be inconceivable without electronic apparatus. This applies to atomic reactions, the flight of jet airplanes, etc.

The development of modern radio electronics can be divided into three principal stages. The first is the time from Popov's work to 1918. This stage is characterized by the use of only long waves in a single practical application – wireless telegraphy. Without electronic tubes, the range of radio communication was limited to hundreds or at best thousands of kilometers.

The second stage (1918 – 1940) is characterized by the rise of radio electronics, i.e., the use of vacuum tubes, the development of radio telephony, and the adoption of short waves. During this stage the range of radio communication increased to cover any possible distance on earth. The radio industry developed vigorously, and many new practical applications of radio were found, including sound motion pictures.

The modern stage of radio electronics is characterized by the adoption of the UHF band and of pulse techniques, by the development of television, and by the latest applications of radio electronics, including electronic automation — automation of the higher type. This stage is characterized by progress in the study of the interaction between electrons and radio waves and advances in solid-state research. These accomplishments are now used to solve problems in the generation of the shortest possible radio waves and the development of electronic devices employing semiconducting, superconducting, magnetic, and dielectric materials, devices capable of replacing vacuum tubes. The advances in this field have changed the appearance of modern radio-electronic apparatus, making it more reliable, more enduring, and simpler to operate.

THE WORK OF A. S. POPOV AND THE INVENTION OF RADIO TELEGRAPHY

Having become interested in Hertz's experiments, Popov began his own research by improving on Hertz's procedure and creating more effective apparatus. In spring 1889 he read his first lecture on "Latest Research on the Connection between Optical and Electrical Phenomena." Popov concluded this lecture as follows: "Man has no organ with which to sense magnetic waves in the ether; if an instrument to provide us with electromagnetic sensing were invented, it could be used for the transmission of signals at a distance."

Although Branly and Lodge were close to inventing radio communication, they lacked the important elements invented by Popov for its realization, namely an antenna, an automatic device for restoring the coherer to its initial state, and an electromagnetic amplifier, devices that made it possible to realize radio communication over distances of practical value.

On May 7, 1895 Popov demonstrated his invention, a radio receiver for the electromagnetic oscillations produced by lightening discharge (there were no other "hams" in those days).

The coherer was automatically shaken by an electric-bell hammer. When the electric bell was operated, its hammer simultaneously struck the coherer and shook it lightly. Thus each signal made the coherer automatically ready for the reception of a new signal.

Popov's first radio transmitter consisted of a spark discharge, connected between the antenna and the ground lead. High voltage from the secondary winding of a Rumkorff coil was applied to the discharge gap. A telegraph key was connected to the primary circuit of the coil, in series with the interruptor.

During the next few years Popov, together with P. N. Rybkin (1864 — 1948) improved the receiving and transmitting apparatus. In 1899, in particular, he introduced telephone reception and in 1900 he replaced the coherer with a detector consisting of carbon in contact with steel. In 1899 — 1900 the radio telegraph was first used for practical purposes.

RADIO TECHNIQUES AND PRACTICAL APPLICATIONS DURING THE FIRST DEVELOPMENT

Advances in the techniques of radio in Russia and abroad led to new improvements in radio transmitters and receivers for damped oscillations. In

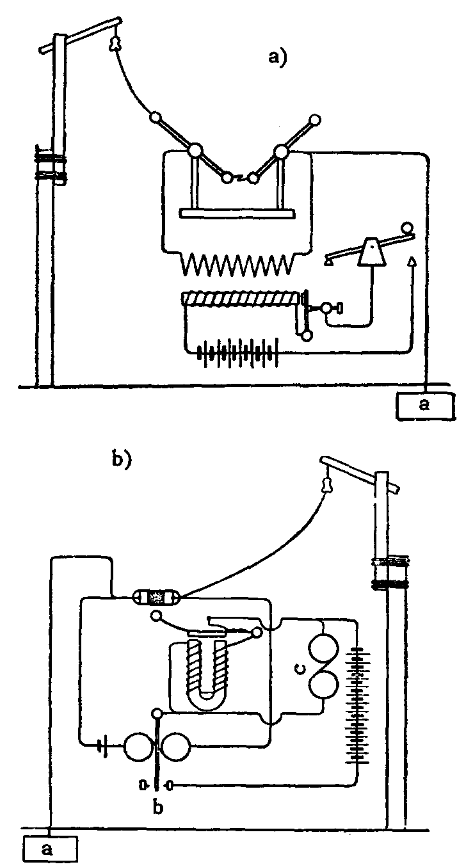

FIG. 1. Popov's radio transmitter and receiver. a — ground, b — relay, c — telegraph.

particular, new types of discharge gaps — of the rotating and of the Wien multiple-disk type — were developed, providing surge excitation, at which the spark was quenched relatively rapidly, so that the oscillations in the intermediate circuit were rapidly damped, thereby reducing the losses.

The range of reliable radio communication reached thousands of kilometers and more. In 1901 G. M. Marconi effected radio communication across the Atlantic.

Before the First World War, undamped oscillations were applied to radio telegraphy, yielding many advantages and paving the way for radio telephony. Undamped oscillations were first produced with arc generators, and later with dynamo generators of the inductor type.

The arc generator worked satisfactorily only on long waves, and the amplitude and period of the generated oscillations were not stable enough. All this made it impossible to use arc transmitters in radio telephony. Radio stations with arc oscillators were built in ratings up to 1000 kw in the wavelength range 7000 — 25000 m for international radio communication.

Goldsmith (1908) and V. P. Vologdin et al. (1912) designed high frequency inductor-type machinery, which was used in large radio stations in conjunction with frequency-multiplying transformers.

In spite of the use of frequency multiplication, no satisfactory dynamo generator was produced for waves shorter than 3000 m, and consequently the rotating generator was found also unsuitable for radio telephony. Several large radio stations for international communication were built in Russia and abroad with rotating generators. The wavelength range of these stations was 5,000 — 30,000 m, and the antenna power reached 500 kilowatts.

Electromechanical interruptors, called tickers, were used for reception of undamped oscillations.

Prior to 1918, the use of electron or ion tubes in radio engineering was quite negligible. Although the diode and triode were produced by Fleming in 1904 and by Lee de Forest in 1905, while Meisner invented the triode oscillator in 1913, only low-frequency vacuum-tube amplifiers and heterodynes for receivers were built prior to 1918. The amplifiers were connected in the detector circuit and increased the sensitivity of the receivers. The heterodyne — a low power oscillator — served for reception of continuous waves, replacing the ticker, and the pitch of the dots and dashes was determined by the difference in oscillation frequency between the heterodyne and the received oscillations. Popov's radio devices, for all the first practical applications, were constructed in the Kronstadt machine shops. However, at that time Russia had no sufficient productive base for further progress in this field.

Only through the efforts of engineers M. V. Shuleĭkin (1184 — 1939), N. N. Tsiklinskiĭ (1884 — 1938), and V. P. Vologdin (1881 — 1955) was a Russian radio plant put into operation in St. Petersburg in 1912. An excellent research laboratory was organized in this plant, which started to produce better radio equipment than the branches of the foreign plants "Siemens" and "Robtit."

A leading role in the development of Russian theoretical work on radio was played by A. A. Petrovskiĭ (1873 — 1942), S. K. Lebedinskiĭ (1868 — 1937), and L. A. Rozhanskiĭ (1882 — 1936).

SECOND STAGE OF DEVELOPMENT OF RADIO ENGINEERING

The advent of radio telephony and the practical application of the short-wave band, which characterize the second stage in the development of modern radio electronics, were made possible only by the great technical accomplishments in the field of theory of design and manufacture of radio tubes. The outstanding role in this matter was played by the Nizhegorod Radio Laboratory, created in 1918 at the resolution of the administration of the very young socialist state. This laboratory served as a first radio institute, in which the greatest specialists of that time were gathered — M. A. Bonch-Bruevich (1888 — 1940), V. P. Vologdin, V. K. Lebedinskiĭ, L. A. Rozhanskiĭ, A. F. Shorin (1890 — 1941), V. V. Tatarinov (1878 — 1941), and others. Within five years they developed and produced five thousand receiving radio tubes and set the first world's record in radio telephone transmission.

The first receiving radio tube, PR-1 (vacuum relay-1), was a triode with a tungsten cathode, a grid of nickel wire 0.2 mm in diameter, an aluminum plane anode operated at 80 — 120 volts. The electrodes were degassed by heating the grid to incandescence with electric current. The design of this tube was based on a deep theoretical and engineering analysis made by M. A. Bonch-Bruevich of the operation of the electronic vacuum tube.

Within an amazingly short time for the prevailing conditions (1919 — 1920), Bonch-Bruevich developed in the Nizhegorod Radio Laboratory transmitting tubes with ratings up to 2 kw (continuous wave), and brought these tubes to an operational state. These tubes were the first to employ water-

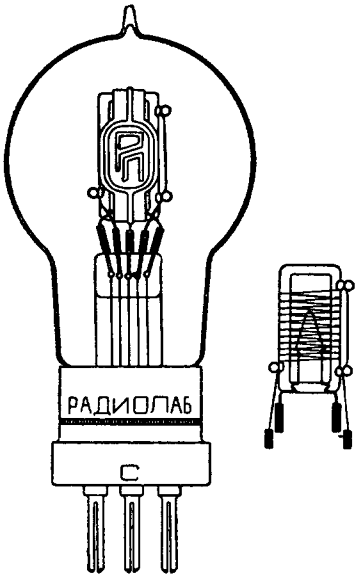

FIG. 2. Receiving-amplifying triode PR-1. Developed by the Nizhegorod Radio Laboratory in 1918-1919.

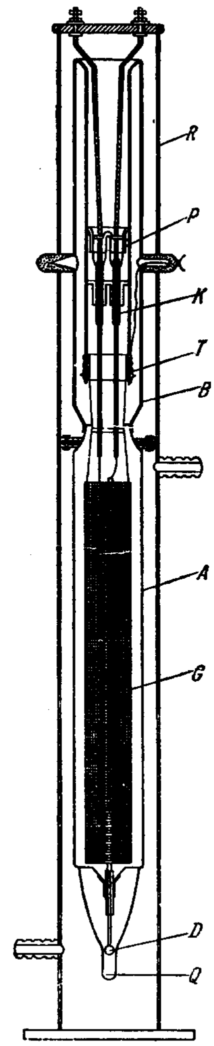

FIG. 4. 25-kw transmitting tube developed by the Nizhegorod radio laboratory in 1923-1924.

cooled plates. They were used in the first radio telephone station (Moscow, 1922).

Immediately thereafter (1922 — 1926) there were developed in the Nizhegorod Radio Laboratory transmitting tubes with water-cooled external copper anodes, rated 25 and 100 kw. They served as the basis for all modern high power vacuum tubes and made possible the development and construction of the first powerful radio telephone and radio telegraph stations in the U.S.S.R.

After 1923 refractory metals such as molybdenum and tantalum became available for the manufacture of transmitting and amplifying tubes. As a result, the Nizhegorod Laboratory developed and mass produced medium power tubes with a rating from 150 to 500 watts, thus making possible the construction of radio broadcast stations for regional centers.

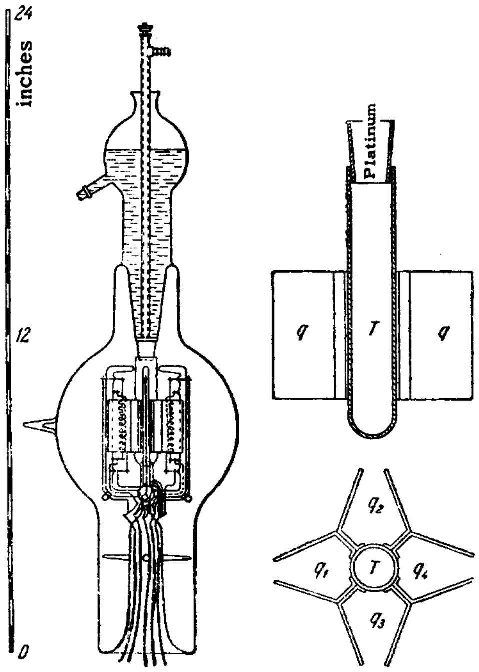

FIG. 3. Transmitting tube rated 1.2 kw. Developed by the Nizhegorod Radio Laboratory in 1919-1920.

Further successful development of the technology and manufacture of vacuum tubes abroad (Langmuir, Schottky) and in Russia (M. M. Boguslovskiĭ, S. A. Vekshinskiĭ, S. A. Zusmanovskiĭ, and others) proceeded along two paths. On the one hand, better characteristics were attained with tetrodes and pentodes, in which the coupling between the control grid and the anode was reduced and the dynatron effect was eliminated in the region of the screen grid and the anode. On the other hand, vacuum technology was improved, making it possible, in particular, to produce receiving and amplifying tubes in metal bulbs. This was accompanied with progress in the theory, construction, and production of other electron-ion vacuum devices, such as cathode ray tubes, kenotrons, or gasotrons.

As soon as the high-power vacuum tube was successfully developed, radio telegraphy emerged from the laboratory. In 1922 the Nizhegorod Radio Laboratory built the first radio broadcasting station in Moscow (the Comintern station), with a rating of 12 kw. This station was the first in Europe and then the most powerful in the world.

During subsequent years the Nizhegorod Radio Laboratory developed a 1.2 kw radio telephone transmitter, the first completely fed from an ac three-phase line; many regional broadcasting stations were built.

In 1925 — 1927 the Nizhegorod Radio Laboratory, under the leadership of Bonch-Bruevich, developed a radio telephone transmitter using 25-kw tubes. It was used in a new radio broadcasting station (Moscow, Shabolovka) with a radiated power of 40 kw. It was in this design that such complicated problems as the realization of high-quality modulation at high power, the suppression of radiation of harmonics by means of an intermediate circuit, etc., were first solved. The separately excited transmitter oscillator consisted of three stages, of which the last one contained three water cooled tubes with a nominal rating of 25 kw each. Modulation was in the plate circuit, and the high-power modulator stage consisted of three similar 25-kw tubes. The plates were fed from a six-phase rectifier and choke-input filter. This was a first attempt at constructing a high voltage mercury arc rectifier to operate reliably with such a filter.

In view of the lack of multigrid radio tubes in those days, audio-frequency amplification for the modulator power stage was a difficult problem. It was solved successfully, however, with the aid of an original circuit, in which the frequency-modulation principle was used. This principle, as is well known, is now used extensively.

Further development in the techniques of radio telephony was under the leadership of A. L. Mints and reached a high level in our country. By the end of the thirties there were developed and constructed radio telephone stations with ratings from 100 to 1200 kw with high quality frequency and amplitude characteristics of the transmitted sound (nonlinear distortion less than 2% from 50 to 10,000 cycles at a 95% depth of modulation) and high stability of the carrier frequency, on the order of 10^{-4}. A multistage transmitter circuit was used, with plate modulation, insuring high efficiency, up to 45 — 50%.

The theory and engineering methods for the design of vacuum-tube radio transmitters reached a high level, thanks to the work of M. A. Bonch-Bruevich, M. V. Shuleĭkin, A. L. Mints, A. I. Berg, and other Soviet and foreign scientists, and it became possible to design transmitters for the long and short wave bands without considerable experimental development.

The adoption of electronics by the radio engineers had a tremendous effect on the improvement of radio receivers. The change from the detector receiver, which was improved after Popov by introduction of an intermediate stage and adjustable coupling, to the "vacuum tube" receiver, has increased not only the sensitivity but also improved considerably many other important characteristics, such as selectivity and interference rejection. The first mass-produced receivers were developed already at the Nizhegorod Radio Laboratory, where O. V. Losev also developed a detector heterodyne amplifier (e. g., crystadyne), an offshoot of which can be seen in modern transistors.

The use of the vacuum tube has led to the development of new circuits and particularly, to regenerative and superheterodyne reception. Thanks to the work of V. I. Siforov, V. I. Kotel'nikov, and other Soviet and foreign scientists, the radio receiving art reached in the early 40's a very high level of development. These investigations made it also possible to apply engineering methods to receiver production. The high frequency stability of heterodyne receivers (reduced to an order of 10^{-5}), the use of ferrite antennas with static shielding, and the use of band filters, including electromechanical filters with a bandwidth less than 1% at an adjacent channel attenuation up to 40 db, made it possible to increase sharply the noise rejection and the selectivity of radio receivers. The use of ferrites, special radio ceramics, and other materials made it possible to improve the design and technological characteristics of modern radio receivers.

Progress in antenna and feeder technology during 1920 — 1940 was based on the work of M. V. Shuleĭkin, M. A. Bonch-Bruevich, I. G. Klyatskin, V. V. Tatarinov, A. A. Pistol'kors, M. S. Neĭman, G. Z. Aĭzenberg, and other Soviet and foreign scientists. Refinements were introduced in the methods of calculating of impedances and capacitances of long-wave antennas; directive short-wave antennas were produced in the form of systems of in-phase half-wave dipoles, and a theory was developed for calculating their radiation impedance. To satisfy the requirements arising in the construction of high power radio broadcasting stations for the medium-wave band, antennas in the form of insulated towers and masts were designed.

Although it was understood even during the first stage of development of radio engineering that the propagation of radio waves over long distances was due to the presence of ionized upper layers of the atmosphere, nevertheless the tendency during those days was to use for long-distance communication long radio waves, (10 — 20 kilometers) at which diffraction plays a relatively large role when propagating over the earth's curvature. Thanks to work by A. Sommerfeld, Van der Pol, M. V. Shuleĭkin, and B. A. Vvedenskiĭ, engineering formulas were derived for diffraction propagation.

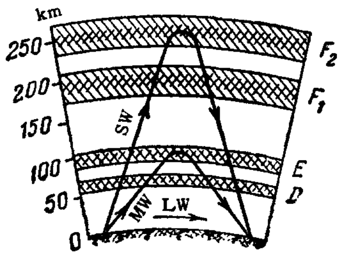

FIG. 5. Ionospheric layers.

The technical mastery and practical utilization of the short wave band began in the 20's. M. A. Bonch-Bruevich, V. V. Tatarinov and others investigated at that time short waves and the "whims" of their propagation, and proposed operation on two wavelengths, one for daytime and the other for nighttime transmission. They also developed the first directive short-wave antennas and organized the first short-wave lines from Moscow to Tashkent and from Moscow to Vladivostok.

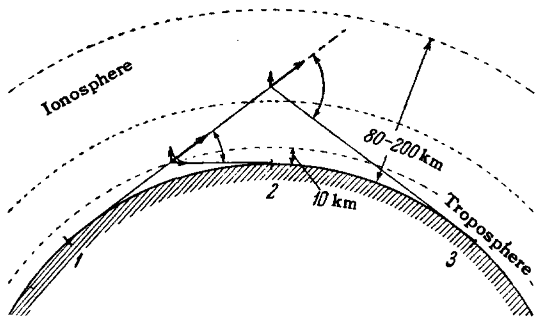

FIG. 6. The propagation of ultra-short waves over long distances due to diffuse scattering.

By the end of the 30's short waves become not only the principal medium for communication relay lines, but were extensively used for radio broadcasting. During the same years, great experimental and theoretical work was performed on ionospheric propagation of radio waves. The work of M. V. Shuleĭkin, M. A. Bonch-Bruevich, A. N. Shchukin and other Soviet and foreign scientists established the presence of several ionized layers (for instance D, E, F_1, and F_2), with gradually increasing ionization density, at altitudes from 50 to 250 kilometers. These layers determine the propagation conditions of long (3,000 — 20,000 m), medium (200 — 3,000 m), and short (10 — 200 m) radio waves. They also established the causes of different states of these layers and of the complicated processes that arise in them (the Gor'kov-Luxembourg effect and others). In addition, they solved in principle the very important practical problem of forecasting the propagation of various waves in the short wave band during different times of the year and during the day, including the "daytime" and "nighttime" radio waves. Experimental investigations of the altitude of layers with different ionization densities was carried out by the radio-echo method, using ionospheric stations especially designed for this purpose.

A study of the propagation of ultra short waves in the meter band, capable of penetrating through the ionized layers of the atmosphere and therefore permitting (with allowances for the influence of refraction) radio communication at the earth's surface within the horizon, was started in the 20's by B. A. Vvedenskiĭ, who derived the so called "reflection" formula, by which the field at the point of reception was determined as the sum of the field of the direct ray and the field of the reflected ray. This and other research on the propagation of the ultra short waves were of great practical value for airplane radio communication, for radar (which came into being about that time), and for the initial development of television.

The second stage in the development of radio electronics was distinguished by great progress not only in scientific work but also as a period when the training of scientific and engineering radio personnel proceeded at a rapid pace. Special radio physics courses and faculties were organized in the universities, and radio engineering faculties were organized in the higher technical institutions of learning. By now their number has increased greatly, as did the overall annual output of radio specialists with higher education.

PHYSICAL PRINCIPLES AND MATHEMATICAL METHODS OF MODERN RADIO ELECTRONICS

At the first stage of its development, radio engineering was based on electrodynamics. The radiation of electromagnetic waves by a current-carrying conductor and their propagation in free space and around the earth was studied by means of Maxwell's equations in the classical differential form. At the same time, processes occurring in ac circuits were analyzed with the aid of classical differential equations with constant coefficients, and the steady states (inasmuch as the wavelengths were large compared with the linear dimensions of the circuits) of the electric oscillations were determined by the integral laws of Ohm and Kirchhoff.

The engineering use of electronic vacuum tubes, microwave frequencies, and pulse oscillations of complex form necessitated the application of several branches of physics and of different mathematical methods. It became first necessary to solve the problems in nonlinear circuits and, in particular, the problems of the transient and steady states of a self-excited triode oscillator. Methods of approximate solution of nonlinear differential equations of radio physics were developed by L. I. Mandel'shtam (1879 — 1944), N. D. Papaleksi (1880 - 1947), Yu. B. Kobzarev, and other Soviet and foreign scientists.

The development of electron-ion vacuum tubes, particularly electronic devices for the generation and amplification of microwave oscillations, was based on the electron classical (not quantum) theory. The equations of motion of electrons in an electromagnetic field, in agreement with the theory of relativity, were used for the design of high power accelerators for charged particles.

The analysis of the response of linear and nonlinear circuits to electric oscillations of complex form, in particular short pulses and frequency modulation, is now based on the Laplace transform, the Fourier integral, and the Heaviside operational calculus. Matrix algebra is used to solve problems in the propagation of electric signals in complex linear circuits, particularly with multi-element filters.

As the linear dimensions of the radio circuits became commensurate with the wavelength, it became necessary to use Maxwell's equations for an analysis of their steady state. It is now necessary to use vector analysis, which facilitates the application of these equations to the engineering of linear circuits at microwave frequencies. The use of nonlinear elements in microwave circuits, with electromagnetic parameters that depend on the magnitude and polarization of the field, has made necessary the use of tensor analysis. In particular, engineering design of ferrite valves, phase rotators, and tunable resonators are solved by this method.

The technology of solid-state electronic devices — transistors, superconducting amplifiers, molecular amplifiers, magnetic and dielectric amplifiers — is based on modern advances in solid-state physics and quantum physics. It is here that we can find the most brilliant examples of the previously-mentioned fruitful collaboration between physics and engineering.

One of the features of modern radio physics and radio electronics is the study and utilization of statistical processes. This includes also the study of radio waves from celestial bodies, the intrinsic noise of radio circuits, detection of weak radio signals, reliability of electronic apparatus, and many other problems. In connection with this, wide use is made at present in radio electronics of methods of mathematical statistics and probability theory.

Requirements for better quality of radio communication, both as regards speed and as regards noise rejection, has called for the formulation of the theory of communication and information. This mathematical discipline engages in a quantitative estimate of information contained in any data whatever and a study of the processes of its storage and transmission. It is to a great extent a branch of the probability theory and, in particular, solves such practical problems as the transmission of maximum of information over a minimum frequency band.

The coming of electronic automation and electronic computing machines has brought forth a new science, cybernetics, which engages in a study of processes in automatic devices and in living organisms. These processes include the storage, accumulation, conversion, and transmission of information. Consequently information theory and mathematical logic become the mathematical foundations of cybernetics.

PROPAGATION, RADIATION, AND CHANNELING OF RADIO WAVES IN MODERN RADIO ELECTRONICS

As already mentioned, the present stage of the development of radio electronics is characterized by an extensive utilization of UHF waves, arbitrarily defined as 10 m to 1 mm long. In connection with this, most experimental and theoretical research on the propagation of radio waves now carried out is essentially in this range.

It is very important to emphasize that only UHF can be used to transmit information in rapid processes (such as television, radar, etc.). UHF transmission makes it possible to use new methods of modulation, pulse modulation (PM) and frequency modulation (FM), raising radio communication to a new level of development both with respect to interference rejection and with respect to speed of information transmission.

UHF waves differ from short and long waves in that they are not reflected (except for waves longer than 5 or 7 meters) by the upper ionized layers of the atmosphere, and are hardly bent around the earth's curvature by diffraction. For this reason, it is impossible under natural conditions, to transmit UHF around the earth without rebroadcasting. For the same reason, only UHF makes possible radio communication in cosmic space.

Experience with radar during the Second World War has disclosed that UHF waves propagate far beyond the horizon, at a distance determined by refraction. Experimental and theoretical research has shown that this phenomenon is due to the sharp reduction in the dielectric constant of the atmosphere, ϵ, with altitude h, and consequently, to the increase in the "effective" radius of the earth, determined by the expression

$$R_{\mathrm{ef}}=\frac{R}{1+R\dfrac{d\left(\sqrt{\varepsilon}\right)}{dh}},$$

in which R is the actual radius of the earth.

Under certain temperature and humidity conditions in the surface layer of the atmosphere, the decrease in the dielectric constant may not be monotonic, and this may cause guided propagation of UHF waves over distances several times the direct distance to the horizon, which is determined by the "normal" value of the effective radius of the earth

$$R_{\mathrm{ef}}\approx\frac{4}{3}R.$$

Diffuse UHF propagation far beyond the horizon has been noted recently and is due to scattering by global irregularities of the atmosphere, a phenomenon which can be called "radio glow," similar to the visible glow due to scattering of light rays by clouds. The troposphere scatters meter waves (shorter than 3 meters), decimeter waves, and centimeter waves (100 – 10,000 Mcs) while the ionosphere scatters meter waves (20 – 60 Mcs). Irregularities in the troposphere are produced by non-uniform motion of air currents of different temperature and humidity. Cumulus-like irregularities in the ionosphere, with relatively high ionization density, are produced essentially by the passage of meteors, by polar aurorae, and by other processes. (When a meteor enters the earth's atmosphere with a velocity of 10 to 70 km/sec, its intense heat rise produces an ionized column of air — a meteor track — which reflects radio waves in this band.)

Experiments have shown that diffuse UHF propagation and reflection of meter waves (in the range from 6 to 75 Mcs) by meteor tracks can be used for beyond-the-horizon radio communication if a powerful transmitter, a very sensitive receiver, and a highly-directional antenna are used.

A characteristic feature of centimeter, millimeter, and partially also decimeter waves is scattering by clouds and absorption in the lower layers of the atmosphere. Scattering by rain clouds and rain fronts is used in meteorology. Since the atmosphere absorbs radio waves corresponding to resonant frequencies of molecules of water vapor, oxygen, and nitrogen, millimeter waves cannot be used for radar.

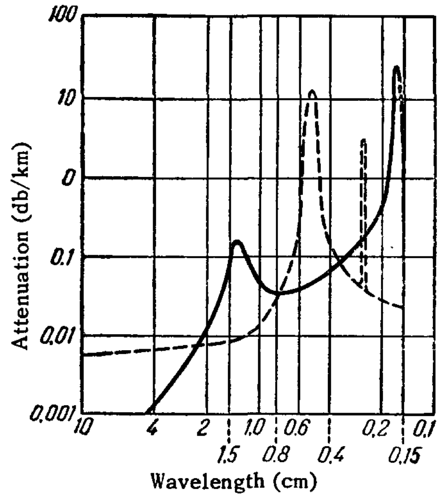

FIG. 7. Absorption of centimeter waves in the oxygen of the atmosphere (dotted) and in water vapor (solid curve).

A new development in ionospheric research, and consequently in the study of propagation of long and short radio waves, is the use of high altitude rockets and artificial earth satellites with automatic electronic apparatus on board. This apparatus yields more details on the distribution of the ionization density in the upper layer of the atmosphere. It has been noted, in particular, that a highly ionized layer exists even at an altitude of 20 km and that 40 km up there exists a layer with a high concentration of mesons and fast electrons. Advances in rocket technology and in the production of artificial radioactive isotopes make it possible to suggest that ionized regions be artificially created in the atmosphere and that their influence on the propagation of radio waves be studied.

It should be noted that since modern long-distance radio navigation uses long waves, and since nuclear explosions and flights of large rockets produce very long radio waves, theoretical and experimental work are still being continued on the propagation of radio waves in this range. Notice should be taken here of the investigations of V. A. Fock, who obtained the most complete and most rigorous solutions to the problem of diffraction propagation over a spherical earth with allowance for normal refraction. Theoretical work is also being done on the analysis of guided propagation of very long waves, corresponding to frequencies of 1 to 20 kilocycles in the space bounded by the spherical earth and the ionosphere, where the impedance is assumed to be different from that of free space.

Scientific and practical problems concerning long-distance propagation of very long waves in the surface layers of the earth and in water are of considerable interest. Other interesting problems are the propagation of short and ultra-short waves in a layer of snow.

An important problem in radio wave propagation, apart from its effective range, is the velocity of the electromagnetic wave near the earth and in free space. An exact determination of the propagation velocity is essential for radar, radio geodesy, and other practical application; it also has an important application in modern physics.

L. I. Mandel'shtam and N. D. Papaleksi have established that electromagnetic waves have the same velocity over a homogeneous surface as in free space, with accuracy to the fourth decimal point. Theoretical and experimental investigations of the influence of irregularities on the earth's surface and roughness of the soil have shown that the direction of wave propagation and the phase velocity are affected only near the boundaries of the irregularity or roughness, and resume their original values away from the irregularity. Using an interferometer at a wavelength of approximately 4 mm, they found the velocity of electromagnetic radiation in vacuo to be 299,792.5 ± 0.1 km/sec.

It is relatively easy to solve scientific and technical problems in the guidance of long and short waves, with the exception of some special cases (the transmission of very high power over a relatively long feeder).

The guidance of UHF currents involves greater difficulties, owing to parasitic radiation, to the surface effect of the current, and to partial reflection of the energy by the load (in the case of a line, whose length is greater than or commensurate with the wavelength). These difficulties are overcome to a certain extent by the use of coaxial and waveguide feeders.

These difficulties are particularly troublesome at millimeter wavelengths, i.e., above 30,000 Mcs. For illustration we can indicate that the efficiency of a copper waveguide 20 meters long at a wavelength of 5 mm is only 0.01%. At the present time research is being carried out[19] on the development of single-conductor lines, strip lines, dielectric waveguides, etc. A particularly promising construction is a spiral waveguide in the form of a tightly wound cylindrical helix made of insulated copper wire. Such a waveguide can carry H_{01} waves, for which no longitudinal current flows in the waveguide and the copper losses diminish with decreasing frequency. The attenuation in such a waveguide may therefore be one-tenth that in a rectangular waveguide.

Considerable progress has been made in UHF antennas, both directional and nondirectional. The efficiency of a UHF antenna is considerably higher than that of a long-wave antenna; at the present time it is possible to build directional UHF antennas with a beam width less than one degree, and consequently the accuracy of measurement of angular coordinates becomes comparable at UHF with the accuracy of optical measurements.[84] In modern

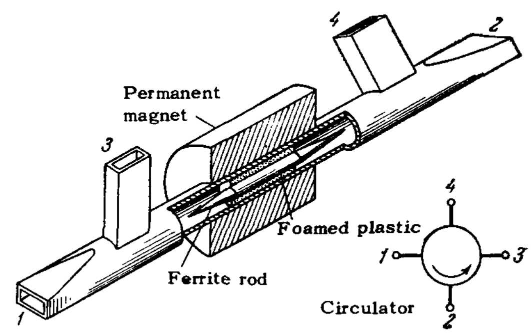

FIG. 8a. Ferrite circulator based on the Faraday effect.

special antennas use is made of rapid scanning of the radio beam at 10 cps and faster. Great progress has also been made in broadband and flush antennas (diffraction, dielectric, surface, lens, etc.).

Inflatable parabolic antenna mirrors with a rigid frame several meters in diameter are used for radar. For the same reason, increased mobility, systems have been developed in which the antenna is an air column strongly ionized by x-rays or by radioactive elements.[84] Small ferrite antennas are extensively used in receivers.[127]

A ferrite long-wave receiving antenna is usually a rod 1 or 2 cm in diameter, 20 — 30 cm long, on which a single-layer or a double-layer coil is wound to form a small receiving loop with a ferrite-core in which the magnetic permeability and dielec-

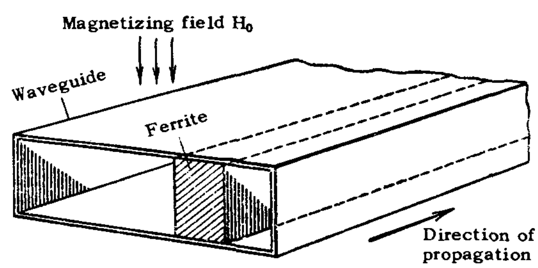

FIG. 8b. Ferrite directional element.

tric constant are considerably higher than in air. Such a loop is therefore the equivalent of a much larger ordinary loop. Antennas for the centimeter band may consist of ferrite rods that radiate energy in an axial direction. By magnetizing the rods with alternating current, it is possible to scan a radio beam in space at a frequency up to several hundred cycles per second.

An effect observed to a great extent in the UHF band is the rotation of the plane of polarization in magnetized ferromagnetic bodies through which an electromagnetic wave is propagated. This phenomenon is now used to design practically inertia-less ferrite switches in the form of controllable polarization filters, rectifiers for electromagnetic energy, circulators to divert the reflected energy to a direction other than that of the incident energy rapidly adjustable resonators, and other UHF circuit elements.

It must be emphasized that the use of directional ferrite elements for the transmission of electric energy is essentially a practical application of electric circuits that do not obey the reciprocity law. This new stage in the development of the theory and practice of electric circuits promises many important practical applications.

GENERATION AND AMPLIFICATION OF ELECTRIC OSCILLATIONS IN MODERN RADIO ELECTRONICS

When UHF currents are generated with the aid of triodes, technical difficulties are caused by the time delay of the electrons and also by electrode inductance and capacitance. Specially designed UHF triodes must therefore be used. One such example is the stacked metal-ceramic radio tube, which can be mounted like an ordinary radio part. A miniature triode[44] of this type, 8 mm in diameter and 10 mm high, can operate an amplifier at 1000 Mcs with a relatively large gain even at temperatures up to 700°C.

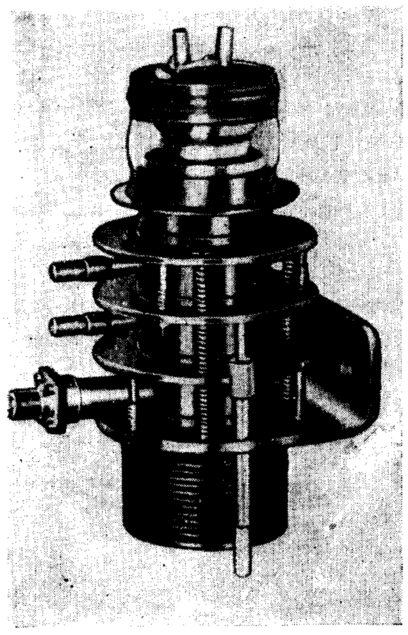

FIG. 9. Large three-cavity UHF klystron.

A characteristic modern trend is also the development of "filamentless" ceramic radio tubes.[128] The oxide cathode of these tubes produces the necessary emission when the entire tube is heated to 500 — 700°C by the thermal losses in the radio apparatus itself or in some other equipment. The other electrodes of such a tube are made of pure tantalum to prevent emission; the use of tantalum contributes also to the absorption of gases liberated in the vacuum at high temperatures. Such tubes can also operate without a source of grid bias, because of the positive contact difference of potential between the cathode and the grid. All this results in a power saving of approximately 80% compared with ordinary tubes with electrically heated cathodes.

To generate large amounts of power in the decimeter, centimeter, and millimeter bands, new types of vacuum devices are being developed and perfected: resnatrons, klystrons, and fixed or adjustable magnetrons.[35-49a]

A very clear example of the progress in this field is the multi-cavity klystron and the megatron type of high-power broadband generator with independent excitation. Unlike the two-cavity klystron, the new klystron has intermediate high-Q cavities; this, along with focusing of the electron beam, increases the efficiency and the gain. Multi-cavity klystron generators with outputs of several tens of kilowatts in the decimeter band, with efficiencies of approximately 50%, and gains on the order of

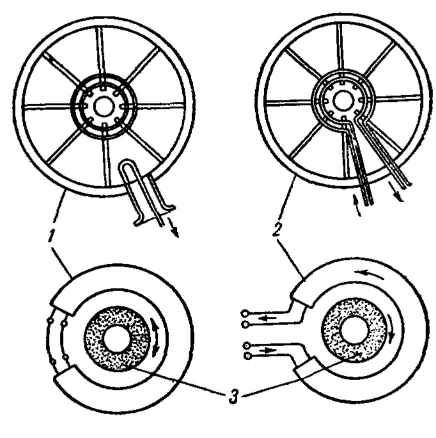

FIG. 10. 1 — self-excited magnetron; 2 — magnetron-type amplifier; 3 — electron cloud.

1000 and above have already been developed. Such high qualities cannot be obtained with tetrodes even in the long wave region. A pulsed klystron[37] of this type has already been developed for a rating of more than 20,000 kilowatts at an average power of 50 kw.

A shortcoming of the multi-cavity klystron is its narrow bandwidth. Free of this shortcoming is the generator-amplifier of the magnetron type, which is capable of amplifying oscillations over a relatively broad range of frequencies, within 10% and more, without a change in the power supply and the magnetic field, albeit at a lower efficiency than the klystron. At the present time decimeter broadband amplifiers of the magnetron type[45] with pulsed power on the order of 1000 kw, an efficiency of approximately 50%, and a gain of ~ 10 in a bandwidth of $\pm 5\%$ have already been developed.

New vacuum devices have been developed and perfected to generate and amplify oscillations in the 300 — 10 mm length range and below. These are the traveling wave tube and the electron wave tube. In these tubes a beam of electrons interacts with an electromagnetic field over a considerable length, and consequently the gain of such a tube is considerably greater than that of a triode or pentode which furthermore, can operate only at lower frequencies. There are now available UHF traveling-wave and electron-wave tube amplifiers with gains on the order of 100 (used to increase the sensitivity of receivers) and on the order of 100,000 (for transmitting and receiving devices in radio relay lines). These tubes have still another valuable property in that they do not let a strong signal pass through. A remarkable property of such tubes is their large bandwidth and that their frequency can be changed almost instantaneously over an entire octave by changing the plate voltage (so-called electronic tuning). A UHF generator with electronic tuning and a broad range is the backward wave tube, in which, unlike in the traveling wave tube, the electron beam interacts with the reflected wave, i.e., with the wave that moves opposite the electron beam. An example of a backward wave tube is the corcynotron, in which the resonator system comprises a corrugated surface, along which an electron beam is moving. By changing the anode voltage it is possible to change the frequency, say from 1600 to 2400 megacycles, at a power rating of several hundreds of watts and an efficiency on the order of 30%.

The electron wave tube employs hollow electron beams; the shaping of such beams, as well as the development of letter-shaped beams and of beams that can be rotated by 180° is proof of the great accomplishments of modern electronics. Included among these accomplishments is the success in producing economical cathodes with high emission density, several amperes per square centimeter of heated surface.

The advances made in electronic devices now permit the construction of radio transmitters for any desired power, and receivers capable of receiving signals with a power flux on the order of 10^{-20} w/cm^2. It must be noted that the power rating of a UHF transmitter is limited by the dielectric strength of the air near the gap of the antenna dipole. On the other hand, the sensitivity of a UHF receiver is limited by the internal and external noise.

In spite of the progress and improvements in electronic vacuum devices, the requirements now imposed on radio electronic apparatus make it necessary to replace the vacuum devices with solid-state devices. Within the next few years the low-power vacuum electronic devices will apparently be completely replaced by semiconductor and other electronic solid-state devices.

The low power consumption, the high efficiency, and the small dimensions of electronic semiconductor devices can be illustrated by many examples. These include: receivers that receive signals from remote radio stations but are supplied with power radiated by a local station; a superminiaturized radio transmitter, which can be swallowed for medical diagnostic purposes; a pocket-size television camera made of semiconductor devices, consuming merely 50 watts, and many others.

In high-power installations, semiconductor diodes are replacing mercury-arc and other vacuum rectifiers. They offer bright prospects of use in industry and in transport, through the development of brushless electric dc machinery and rectifiers, both for high voltages on the order of several hundred kilovolts, as well as for low voltages but rated at hundreds of thousands of amperes.

Particular emphasis must be placed on the promise offered by semiconductor amplifiers with built-in power supply in the form of modern cheap radioactive materials. The technology of semiconductor devices has now reached such a level, that it has become possible to design semiconductor devices that combine the functions of a triode, capacitor, and a power supply. Thus, a small solid body can serve as an amplifier without a source of supply.

It should be noted that the Hall effect is some

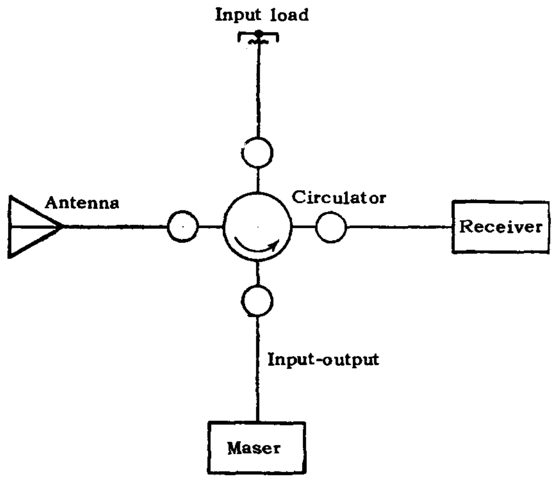

FIG. 11. Circuit diagram of molecular amplifier with ferrite circulator.

hundreds of millions times stronger in a semiconductor. This phenomenon can be used to produce dc diodes analogous to ferrite microwave diodes, and also to produce various converters (transducers). There are no transistors as yet suitable for practical generation and amplification above 100 Mcs. However, research in this field has already produced experimental models of low-power semiconductor generators and amplifiers[75,78] for frequencies up to 3000 and even 10,000 Mcs.

Note should also be taken of the successful development of a new type of solid-state generator-amplifier, namely the quantum-mechanical (also called molecular) generator-amplifier,* in which the amplification is produced by the interaction between the electromagnetic field and the internal energy of atoms or molecules, unlike the vacuum and semiconductor devices, in which the interaction is with the free electrons. By artificially increasing the number of particles ("population") in the uppermost energy level through the introduction of an electromagnetic field of increased frequency, conditions are created for amplification of the lower-frequency signal.

A molecular solid-state generator-amplifier consists of a crystal of paramagnetic substance, placed inside a UHF resonator with constant magnetic field. To increase the difference in "population" of the levels, and consequently to increase the gain, the paramagnetic crystal is cooled to temperatures close to 0° K, and this results in a very low level of internal noise.

Laboratory models of molecular amplifiers are already available for the centimeter and decimeter bands; these employ two or three energy levels. In three-level models, to amplify frequencies on the order of 3,000 Mcs, an excitation frequency on the order of 9,000 Mcs is used at several milliwatts. If the input signal is 10^{-11} to 10^{-10} watts, the gain obtained in this case is 10 to 30 db. Used as a preamplifier, the molecular amplifier can increase the sensitivity of a radar receiver by a factor of a thousand; it is easy to vary the frequency over a sufficiently wide range by changing the intensity of the constant magnetic field.[62-65]

It is believed that a molecular amplifier operating at 21 cm and used in a radio telescope can resolve the problem of the presence of "hydrogen clouds" between the galaxies.

Connecting a molecular generator between an antenna and the input of a radio receiver necessitates the use of a circulator, specifically a ferrite one, since the input and output of the amplifier signal are combined in it.

In connection with the development of the technology of very low temperatures, superconducting devices capable of performing many of the functions of transistors in radio electronic circuits are presently being developed and have already found practical use. One particular superconducting device, the cryotron, consists of a piece of tantalum wire kept at −240°C, the superconductivity of which can be destroyed by a magnetic field, arising when a weak current is made to flow through a thin niobium winding wrapped around a section of the tantalum wire.

The prospects of developing high power semiconductor and solid-state electron devices for the generation and amplification over the entire range of radio frequencies, including the UHF band, are still not certain. Many unsolved problems such as obtaining the necessary materials, developing efficient designs, and overcoming technological difficulties retard the development of such devices. No way has yet been found to produce solid-state electronic devices capable of replacing vacuum cathode ray tubes. However, progress in solid-state physics gives grounds for assuming that even these problems will be solved shortly.

Great progress has been made recently in the development of nonlinear magnetic and dielectric materials, which permit the production of low, medium, and ultra high frequency high-power tubeless amplifiers. A remarkable accomplishment in this field is the development of a magneto-dielectric material, ferrite, one application of which has already been mentioned. This material has ferromagnetic properties but is not a conductor. It therefore is not subject to eddy-current losses,

*The name used abroad is MASER, which stands for "microwave amplification by stimulated emission of radiation."

which limit the application of ordinary ferromagnetic cores in high-frequency and UHF circuits.

Another remarkable accomplishment in this field is the development of ferroelectric-dielectric materials. A capacitor with a dielectric made of ferroelectric material is capable of retaining its residual charge even if its electrodes are short circuited. When the polarity of the applied voltage is reversed, the residual charge produces a rectangular hysteresis loop.

It must be emphasized that the problem of increasing the operating reliability of radio electronic apparatus has assumed great importance at the present time. This is due to the extensive use of electronic apparatus for very important functions. This has given rise to a new discipline, which involves the study of reliability of radio-electronic apparatus and makes use of probability theory.

A most important current problem in the field of construction of radio-electronic apparatus is miniaturization. To increase the reliability of radio-electronic apparatus and to miniaturize it involves not merely replacement of vacuum devices by non-vacuum ones, but also improvement of all radio components. Much has been accomplished recently in this direction. Printed circuits and new radio materials make possible the production of reliable miniaturized electronic apparatus with components — resistors, capacitors, transformers, selsyns, etc. — that can operate even at 600 — 800° C. Another important problem is the development of materials that are transparent to radiowaves (for use in antenna radomes and for the nose parts of rockets) capable of withstanding temperatures above 1000° C.

PRACTICAL APPLICATIONS OF MODERN RADIO ELECTRONICS

1. An outstanding feature of modern radio communication is the progress in high-speed radio telegraphy. Up to 100,000 words a minute can be transmitted with a special cathode ray tube. The operation of such a tube is similar to the typesetting process: it converts coded signals, say from magnetic tape, into sharply outlined letters and numbers on a screen.

UHF long-distance radio communication has a very promising future. Its technical means are radio relay lines and stations that use diffuse propagation of UHF. The advantages of long-distance UHF radio communication are: reliability of operation during any time of the day or of the year (up to 99.9% of the time during which the signal-to-noise ratio exceeds unity), high rate of interference rejection, and a large bandwidth to accommodate many telephone and television channels. A combination of radio relay lines and diffuse-propagation lines will probably be the principal means of communication in the near future, and the short- and long wave bands will be relegated to an auxiliary role.

The transmitters used in communication systems based on diffuse propagation in the ionosphere are rated 20 to 50 kw, and antennas have a directivity pattern of 5 to 20°, insuring a range up to 2000 km.

Using transmitter ratings of 1 kw and antennas with a small directivity at meter wavelengths, radio communication is possible by reflection from meteor tracks, which have lifetimes ranging from milliseconds to several seconds.[86] The length of the track (usually approximately 10 km) permits a communication range up to 2,000 km. Telegrams are first recorded on magnetic tape and are automatically transmitted at very high speed (several thousand words per minute) during the lifetime of the meteor track. Since hundreds of meteors enter the atmosphere hourly, such a rate of communication is quite productive. If the track lifetime is very short, the transmission of the corresponding portion of the telegram is automatically repeated.

FM klystron transmitters rated 1 to 10 kw are used in diffuse propagation in the troposphere. The antennas are parabolic reflectors up to 20 meters in diameter; the communication range reaches approximately 600 km.[9-94]

Diffuse propagation of decimeter waves makes it also possible to increase the operating range of air-to-ground communication. For example, at a flight altitudes of 5,000 meters it is possible to communicate over distances of approximately 700 kilometers.

The advances in modern television are numerous. High-sensitivity transmitting tubes of the orthicon and superorthicon type permit studio broadcasts without special high-intensity illumination, or transmission from outside the studio under ordinary illumination. Other, more sensitive transmitting tubes of the "vidicon" and "ebicon" type, in which the variable conductivity of a semiconductor target is used, permit television transmission even in faint moonlight.

A recent development is a combination cathode-ray and traveling-wave tube to serve as a receiver for the centimeter band. Such a tube is connected directly to the antenna and has a very high sensitivity and a relatively low level of internal noise.

The design and technology of color receiving tubes are being constantly improved. One particular receiving tube has a screen made of alternating vertical strips of luminophors for the principal colors; such a tube is easier to manufacture than a tube having a screen with regularly arranged luminophor grains.

Work is in progress on a flat television screen in the form of a dielectric plate, covered with luminophors capable of glowing in an electric field. Such a luminophor layer is placed between two mutually-perpendicular sets of thin parallel conductors. A glowing point appears on the screen at the intersection of any two wires to which a video pulse (from the television receiver) is applied at any given instant.

In view of the success of diffuse UHF propagation for long-distance radio communication, and in view of the growth of radio relay networks, television transmissions on an international scale are expected in the near future.

At the present time television is very extensively used in industry, nuclear engineering, underwater operations, military apparatus, etc. Television apparatus is already used to demonstrate model manufacturing processes, to display surgical operations, etc.

Television is particularly indispensible in dangerous technological processes and in underwater operations. Underwater television cameras are now capable of operating at a depth of 1,000 meters.

To permit remote manipulation in dangerous technological processes, it is possible to employ stereoscopic television apparatus, which would permit judging the distances between the "hands" of the manipulator and the object.

2. Modern radar equipment operates in decimeter, centimeter, and millimeter bands. Position is located by modern radars with a relative error of less than 10^{-4}, something that cannot be attained with other technical means.[91-94]

Many types of modern radar can measure angular coordinates with an error of less than 2 or 4 minutes. Special-purpose radio direction finding devices, particularly for radio astronomical observations, can measure angular coordinates with an error of several seconds, the same accuracy as obtained with optical instruments.

Modern radar devices also have very large resolving power, reaching hundredths of a microsecond or several meters in millimeter-band radar using pulses on the order of several hundredths of a microsecond.

The operating range of the best modern radars may reach several thousand kilometers, thanks to the use of large antennas, high power transmitters, and sensitive receivers. The sensitivity of radar receivers is increased with integration methods and with molecular amplifiers having a low intrinsic noise temperature.

A radar system using the Doppler effect can spot a moving target against the background of reflections from clouds, local objects, and artificial noise.

Radar apparatus is now extensively used to control airplane traffic near an airport, for "blind" landing, and to control the movement of the airplanes in an airport. There are numerous other applications of radar control in transport, including control of automobile traffic.

A unique feature of modern radar is the use of electronic computing devices, which replace the visual indicators and the work of the human operator. In some military and civilian applications of radar, the information developed by the radar is so complicated and accumulates so rapidly, that its interpretation and utilization — the derivation of suitable solutions from the data — cannot be performed by humans within a practical time limit.

Radar operating in conjunction with an electronic computer can automatically track an attacking object such as a fighter or a guided missile, control a long distance rocket, or control cosmic rockets.

It must be emphasized that radio-telemechanical control, as such, was born soon after the invention of wireless telegraphy. However, only the development of radar, which permits "seeing" (observing) the controlled object at distances exceeding the range of the human eye, has made radio control of moving objects feasible.

The time is not far when radar and radio control will make possible the flight of cosmic rockets with electronic automatic apparatus on board, offering a ground observer full possibility of studying phenomena in cosmic space. One can state, in connection with this, that human presence in cosmic space, at least for the purpose of investigating the universe, will become unnecessary.

Radio navigation apparatus has now reached a high degree of perfection. A widely-used range-finding system based on the principles of radar and modern radio navigation has a much greater accuracy and range than the angle-measuring system.

In the "pulsed circular system," the location of a ship or an airplane is determined by measuring the distance from two surface radio targets.

When operating at UHF, the operating range reaches 500 kilometers, and the error in position determination is approximately 20 meters. In the "pulsed hyperbolic system" the location is determined from the difference in distances from three surface transmitting stations, which radiate synchronized high-frequency pulses, received in a ship or on an airplane. When operating with long or short waves, the operating range reaches several thousands of kilometers, at an error of 20 km and less. Measurement of the phase of the carrier frequency makes it possible to determine coordinates with greater accuracy, and to reduce the error to less than 100 meters.

To make radar systems autonomous, i.e., free of the need for surface stations, a Doppler systems is now under development. Such a system consists of an airborne radar that radiates in three directions.[102-105] By comparing the frequency of the reflected signals with the radiation frequency it is possible to determine the ground speed accurate to ±1% and the drift angle with an accuracy on the order of ±0.5%, and to determine from these data the location of the airplane and the shortest course to the destination. All these data can be computed automatically with electronic apparatus, and the pilot can therefore visually observe all the navigational data on the airplane-control indicator.

Artificial earth satellites will probably soon be used for radio navigation of airplanes and ships. Radio signals from three such satellites will make it possible to determine the ground position by relatively simple radio means, with high accuracy, and in all weather.

Methods for very accurate measurement of distances, as developed by radar, are being used also in geodesy. Radar apparatus is used in geodetic and cartographic operations for accurate determination of the position of the airplane that takes the aerial photographs, or for guiding it to the required region.

Distances on the order of 30 — 50 km between two points on the earth's surface can be measured with relatively lightweight portable continuous-wave radar operating at wavelengths on the order of 10 cm modulated at several frequencies from 9 to 10 Mcs. By changing the phase shift of the modulating frequencies it is possible to determine distance with very high accuracy (error on the order of ±5 cm).

To measure relatively short distances, pulsed lightweight systems are used, based on the same principle as radar but using optical waves. At the present level of pulse techniques, when electric pulses shorter than 0.01 μsec can be generated, optical location apparatus makes it possible to measure distances accurate to less than one decimeter.[100]

It must be emphasized that the use of radar makes it possible to accelerate complicated geodetical plotting, and reduces to one tenth the time of geodetic plotting of large unchartered areas.

Rain clouds and storm clouds are located by radar stations operating in the centimeter band with circular scanning and with vertical scanning. The indicator screen of such a station shows the formation and movement of storm fronts over areas of tens of thousands square kilometers. Only with the aid of high-speed electronic computers can the meteorologist use the large amount of information provided by meteorological radar.

Concluding the section on radar, let us note the technical feasibility of the so called "passive" radar, similar in its physical principle to thermal direction finding.[129] At relatively low temperatures, −20 or −30°C, a noticeable portion of the thermal radiation consists of centimeter and millimeter radio waves. Since a radar receiver operating in this band can be made more sensitive than a detector of infrared and heat rays, and since radio waves are less absorbed in the atmosphere, it is possible in many cases to detect certain objects by radar without the use of a special transmitter, i.e., operated essentially as a direction finder for thermal radio waves. Thus, for example, such a radio direction finder operating at 0.8 — 3 cm can detect objects when the apparent difference in their temperatures is 2 or 3° K. This makes it possible, in particular, to "see" the travel of a ship, since the water in the wake is warmer than the surrounding water; it is also possible to "see" the shoreline from an altitude of 2,000 m in thick fog. Naturally, the resolving power of such a radio direction finder is considerably lower than that of a thermal direction finder, and its operating range is less than that of a radar that has its own transmitter. Nevertheless, one can assume that this newly developed method of radio detection will find extensive practical application.

3. Since UHF waves penetrate through the ionosphere and are hardly absorbed in the lower layers of the atmosphere, a UHF receiver with a directional antenna can receive radio waves from celestial bodies. The observation of such radio waves yields many new data unobtainable with optical instruments.

In view of the low density of the power flux in the radiation from celestial bodies (approximately 10^{-18} w/m^2) it becomes necessary to use large antennas (100 m^2 and above). But even in this case the power at the input of the receiver is much lower than the level of the intrinsic noise of a modern ultra sensitive receiver, which is usually designed for the reception of short-duration signals. On the other hand, by using the radiometer method, which is suitable only for reception of prolonged signals, it is possible to register and measure the weak radio radiation from celestial bodies.

In spite of its brief history, radio astronomy already has many scientific and practical accomplishments to its credit. Thus, radio waves have been observed at wavelengths of 8.6 — 12 mm from the moon and at wavelengths of 30 mm from Mars. This permits an estimate of the nature and temperature of the upper layers of the surfaces of these planets.

Strong radio signals, radiated by several sources on Jupiter in the 18 — 20 Mc band, lasting from fractions of a second to several seconds, have been observed. The energy in these signals is some 100,000 times greater than that of a strong lightning discharge in the earth's atmosphere.

Radio waves from the galaxy and metagalaxy have been discovered, and many individual sources (radio nebulae) which produce no visible radiation have been detected.

Radiation has also been observed at a wavelength of approximately 21 cm, the source of which is interstellar gas — strongly rarified hydrogen.

It is possible to measure the distribution of the intensity of radio waves over the solar disc, along with regular observations of radio waves from the outer corona of the sun, while optical observations of outer corona are possible only during total solar eclipses.

The effective temperature of the earth's atmosphere in clear and cloudy weather was measured at wavelengths of 3.2 cm and 8.7 mm under different elevation angles. It varies from 90 to 50°K at 3.2 cm and from 40 to 200°K at 8.7 mm.

Radio astronomical observations make it possible to develop new navigational instruments — radio sextants, i.e., instruments used to determine the position of a ship or airplane from radio observations on celestial bodies (the sun or the moon).

More detailed observations of meteoric tracks can be made during any time of the day and in all weather by means of relatively simple radar apparatus.

Many radar observations of the moon have been made to date at various wavelengths ranging from 2 m to 10 cm. It is necessary to use for this purpose relatively powerful and sensitive radars. The results of these observations, in addition to producing an accurate measurement of the distance to the moon, yield information on the reflecting properties of the moon's surface, on its libration, and on the electron concentration in the ionosphere. In particular, these observations have established that UHF waves are reflected principally only by the central region of the moon's disc, approximately $\frac{1}{3}$ the radius of the disc, with a reflection coefficient — albedo — of approximately 0.1. We can conclude from these data that the use of reflections from the moon for radio communication between remote points on the surface of the earth is possible only when the signal frequency spectrum does not extend beyond 1,000 cps, i.e., of practical use only for radio telegraphy.

Radio electronics is also extensively used in optical astronomy the technical means of which it has perfected and extended. The sensitivity of astronomical observations is now increased through the use of the storage features of the television tube. It is possible to obtain by this method photographs of the solar disc in ultraviolet or infrared illumination. No less successful is the use of television with a refractor to observe the moon, Jupiter, and Saturn. This has made it possible to obtain large and sharp images of the cloud rings on Jupiter and the small craters on the moon.

Of great value to the improvement of astronomical observations are newly developed electronic light amplifiers. These make it possible to reduce by hundreds of times the exposures needed to take photographs with a telescope. This is equivalent to increasing the possible viewing distance.

There is no doubt that radio astronomy, radar, and the launching of cosmic rockets with automatic radio electronic apparatus represent a new stage in the human study of the universe. Artificial satellites and the first cosmic rocket of the U.S.S.R., together with all the earlier results of radio astronomical and radar observations, are a successful beginning in this stage. One can even state that these methods, within a relatively short time, have already yielded more information than has been accumulated by humanity during its entire history.

Another new science resulting from the development of UHF techniques is radiospectroscopy, which engages in the study of the microcosmos, unlike radioastronomy, which investigates the macrocosmos. The physical process studied by radiospectroscopy is the selective absorption of certain radio waves in the UHF band by various substances. Radio spectroscopy not only extends the capabilities of spectral analysis (which uses waves in the optical band), but makes it possible to study the detailed structure of molecules. Because of the use of electronic circuits that generate and amplify monochromatic electric oscillations, radio spectroscopy greatly exceeds optical and infrared spectroscopy in measurement accuracy and resolving power.

Selective absorption of radio waves by molecules of various substances is also used to stabilize the frequencies of generators operating in the millimeter and centimeter bands.

The study of molecular structure by radio spectroscopy has led to the development of a new method for generating and amplifying UHF oscillations — the mulecular generator and amplifier. We already mentioned the solid-state molecular generator-amplifier. In the gas molecular generator for the millimeter or centimeter bands, the molecular ammonia beam travels through vacuum in a strong electric focusing field; this separates the molecules with the higher energy levels and guides them into a cavity resonator, in which they excite resonant oscillations. The great practical advantage of this generator is that it has a very high frequency stability, on the order of 10^{-12}, and can be used as a frequency standard and therefore as an instrument for measuring time intervals very accurately.

A molecular clock based on this principle can measure time to better than 10^{-11} sec. By using a molecular clock in a long-range radio-navigation system, it is possible to measure a distance of several thousands of kilometers from the base, accurate to within several times ten kilometers.

The high-frequency stability of molecular generators uncovers new possibilities of investigating various physical phenomena, making it possible in particular to check experimentally the general theory of relativity, since the gravitational frequency shift in the earth's field equals, near the earth's surface

$$10^{-10}\nu\frac{h}{R},$$

where h is the vertical distance between sources and ν the radiation frequency.

4. Radio electronic apparatus is now indispensible in various applications of atomic physics and engineering. At the present time the method of "tagged" atoms is very extensively used for various types of analysis. The radiation from such atoms is registered by special electronic circuits, which also carry out amplitude and frequency analysis of the electric pulses produced by the radioactivity.

An accelerator for charged particles is essentially a high power electronic device, in which the energy of the high frequency electromagnetic field is converted into energy of moving charges, i.e., the opposite of a high-frequency electronic generator, in which the energy of a (constant) field is converted into energy of an alternating current. An example of a high-power accelerator is our own 10-Bev proton synchrotron, with a magnet 60 m in diameter and an overall power consumption of 150,000 kw. An even larger accelerator is now being developed in the U.S.S.R., rated 50 Bev. The annular orbit of the accelerated particles in this proton synchrotron will be approximately 1.5 km long.

Research has been started on methods of converting the energy liberated in nuclear reactions directly into alternating-current energy. The electrons and protons liberated in the atomic reactor can be bunched by an electromagnet into particle beams of periodically variable directions, thereby inducing alternating current in an electric circuit.

Mention must be made here of the research in progress on the conversion of thermal energy into electricity through the use of thermionic emission.[111] The efficiencies obtained in laboratory models of such generators (consisting of a bulb with two electrodes having different work functions, filled with an ionized medium) are already on the order of 10%, and it is assumed that this efficiency can be increased considerably in the future. As is known, the efficiency of conversion of heat into electricity by means of a thermocouple is 1%. The absence of mechanical contact between electrodes in a thermionic converter would make it possible to maintain a greater temperature difference between the electrodes, thereby insuring a higher conversion efficiency.

In contrast with the controlled nuclear reaction, which is realized in atomic reactors with the aid of chemical and mechanical technologies, a controllable thermonuclear reaction can be realized through the use of electronic technology. First steps in this direction have already been made: to attain the temperatures necessary to realize a thermonuclear reaction, use is made of electric pulses of tremendous power in a gas placed in a strong magnetic field. The field pinches the discharge into a thin streamer, thereby insuring its thermal insulation. It is not excluded that the use of a UHF electromagnetic field in a suitably designed and constructed thermonuclear reaction would provide both the necessary heat rise and the necessary thermal insulation of the plasma, in which the fusion reaction would take place.

The use of electronics in atomic energy would enable us to build cosmic rockets with a range not only within the confines of our own solar system, but beyond it. Ionic and photonic rockets, based on the use of the escaping of ions and photons, are already in development. Thus, for example, a rocket is now being designed,[114] propelled by the reaction of a "jet" of ions with velocities of 200 km/sec. In this rocket heat from an atomic reactor will be converted into electricity to ionize cesium vapor. Strong electric fields will force these ions through a nozzle at the aforementioned velocity.

High frequency currents for industrial heating are now used extensively in industry. Since the power absorbed by a dielectric increases with increasing frequency of the alternating field, the use of UHF for heating nonmetallic parts and materials is very effective. This method makes it possible to heat essentially the internal portion of the treated object. High-frequency induction heating is used to heat metal parts, placed for this purpose in a magnetic field. In this case, owing to the skin effect only the outer layers of the parts are heated, and if the action is rapid enough the inner layers do not have time to become heated by conduction. This phenomenon is used for surface hardening.

High frequency heating methods have found a valuable application in medicine, where they have been called short-wave and ultra-short-wave diathermy. There is hardly a medical institution at present without electronic equipment for various diagnostic, analytic, and therapeutic purposes.

There is hardly any branch of industry that does not employ automatic control of some technological process through the conversion of nonelectric quantities into electric ones by means of various transducers — capacitive, inductive, resistive, electrochemical, photocells, and those employing television techniques.

Electronic strain gages with wire transducers make it possible to measure stresses in various parts of large machines. Electronic circuits enable us to maintain automatically a given temperature in a furnace with high accuracy, to measure negligibly small displacements, and to carry out chemical mass analysis during a continuous manufacturing process. Continuous measurement of the thickness of a rolled strip is made possible by electronic devices, that register β or γ rays from radioactive isotopes placed near the measured strip. The humidity of paper is controlled during its manufacture by electronic humidity meters that operate on the variation in the output voltage of a high frequency oscillator whenever the capacitance of its tank circuit changes with changing humidity.

A very great variety of radio electronic apparatus is used by the printing industry, by motion picture factories, etc. Automatic plants for mass-production parts, concrete, and many other materials, are operated by electronic control. Radio control of lifting cranes and other high-power construction equipment is gaining wide use.

Electronic apparatus is used extensively in geology to prospect for minerals. Experiments are being carried out on the use of rapid high-frequency heating to break up large blocks of mineral rock.

5. The present-day need of easing human mental labor and demands imposed by the control of complex technological processes or by military engineering problems can be satisfied only by electronic automation, automation of a higher type, characterized by the use of feedback and memory devices in both the program and the output. An example of an electronic automatic device is the electronic (digital) computer, which can perform complex mathematical and logical operations at very great speed, and which also makes possible continuous control and regulation of complex technological processes to a high degree of accuracy.

In many fields of science and technology there are computational problems that can be solved only after dozens of years of continuous calculations by a large staff. An electronic computer, capable of performing tens of thousands of arithmetic operations per second, can solve such problems in several hours to a required accuracy. However, more and more new demands imposed by modern development of science and technology make it now necessary to develop electronic computers capable of performing up to two million additions or 500,000 multiplications of 12 — 15 digit numbers per second.[130]

Simple electronic circuits have, in principle, amazing properties. The generation of short pulses is really a process in which current is turned on and off in a circuit with a small time constant; the remembering of information really represents pulsed charging of a miniature capacitor or pulsed magnetization of a miniature core. The logical operation of multiplication is really the production of a pulse on the anodes of two tubes connected in parallel, when positive pulses are applied simultaneously to their cathodes. The result of all this is the outstanding accomplishment of modern science and technology, an electronic device that performs the functions of human mental labor.

In an electronic digital computer all operations are carried out by counting electric pulses that last a microsecond or less. The use of the binary system in electronic computers insures stability and high speed of operation; if $1/2$ microsecond pulses are used, an electronic computer can write down the number that represents one billion in approximately 30 microseconds, i.e., some 200,000 times faster than writing by hand in the decimal system.

The block diagram of an electronic digital computer includes the following principal parts: input unit, arithmetic unit, memory units, control unit, and output unit. In the input units, the computation programs and the initial data, initially recorded in the form of a numerical table, are rerecorded in binary system on punched cards.

The conversion of a numberical table into a system of holes in punched cards can be made automatic with the aid of an automatic electronic reading machine. The automatic machines already developed, can read more than 100 digits (from 0 to 9) per second, and can thus keep up with a high-speed electronic computer. The operating principle of the automatic reading machine is based on breaking up the digit into several elements, in each of which either black or white predominates. When a light beam scans the digit, a group of electric pulses is transmitted from each digit by a photocell. This group is converted by means of special circuit into a single pulse at a corresponding output terminal of the unit. The number of output terminals equals the number of digits to be read, i.e., ten.

To increase the productivity of a high-speed digital computer, the output data are printed and are simultaneously duplicated by high-speed automatic electronic apparatus with character-displaying cathode-ray tubes. The characters are transferred on paper by xerography. Such automatic equipment can operate at a printing speed of more than 2,000 characters per second.

The principal parts of an arithmetic unit are electronic circuits for addition, subtraction, and multiplication. The basic elements of such circuits perform the following basic logical operations: negation ("no"), logical multiplication ("and"), and logical addition ("or"), Logical multiplication in particular, is effected by an electronic circuit called a coincidence circuit.

It must be noted that in modern large electronic computers the internal memory devices, which comprise cathode-ray tubes or ferrite cores, can remember up to several thousands of numbers, each of which can be recorded or retrieved in any sequence. External magnetic-tape memory devices may have, in the case of large machines, a capacity on the order of several million numbers, but the stored numbers can be retrieved only in a definite sequence.

As already noted, electronic digital computers permit automatic control of complex processes, for example control of machine tools, electric power stations, and aircraft, rocket, or missile flight.

In an automatically controlled milling machine, the shape of the part to be milled is specified in terms of numbers represented by holes in a punched tape. The electronic computer uses these numbers to generate commands in the form of voltages applied to the electric motors and servomechanisms that actuate the cutting tool and the milled part. During the control process, the electronic apparatus performs rapidly a large number of computations, comparing the actual dimensions with the specified ones and generating control signals on the basis of this comparison. Automatic control of a milling machine with the aid of an electronic computer reduces the time required to finish complex parts to almost one third the time required with tracer-equipment. In addition, the replacement of tracer equipment by punched tape reduces greatly the length and cost of the setup operations.

When an electronic digital computer is used for automatic control of the flight of an airplane, the computer controls the takeoff, levels the airplane at a given altitude, guides it along a specified course, brings it to the specified point, and controls the landing. The flight program is calculated beforehand and recorded on punched tape. The electronic computer compares the aircraft-position data, as given by navigational instruments, with the flight program and corrects the course if there is any. If dangerous thunderstorm formations are encountered, as detected by a special radar, the airplane is guided around the storm area over the most suitable course.

An electronic digital computer is capable of performing the operations that make up the process of solving a logical problem, i.e., operations of remembering given information, comparison of received information with the remembered information, and the production of an answer based on this comparison. Thanks to this, for example, the electronic computer can translate text from one language to another, delivering the translation in printed form.

In the future it will be possible to build electronic digital computers capable of automatically translating a speech simultaneously into several other languages and radio broadcasting the translations to a mass audience. In addition, the present day state of radio electronics makes it possible to envisage an electronic reading automat, which would reproduce text acoustically in one of several specified languages, and also of an automat which would record human speech on a typewriter in any prescribed language.

The use of electronic digital computers for playing checkers or chess, the creation of self-teaching machines, etc., are experimental research topics in cybernetics. This research is of inestimable importance to the development of biology, including the study of processes of the upper nervous activity. It would make possible not only a more thorough study of the living organism and improvement in its viability, but would also lead to better automatic devices capable of the performance of the more complicated functions of human mental labor.

A hydraulic pump, controlled by an electronic computer and capable of taking into account the state of the blood and other physiological reactions, could replace the heart in the living organism during the time of a complex operation. An ultrasonic locator, the output signal of which is first analyzed by a high speed electronic computer and is then converted into electric pulses fed to suitable sensitive points, may serve as a guide for a blind person.

By studying the electric oscillations — biocurrents — that occur in the human organism during the activity of its brain, it is possible in principle to analyze and synthesize not only physiological processes, but also the thinking processes. Were we, for example, to succeed in discovering and decoding the electric pulses that arise in the brain both while speaking aloud and during unvocalized expression of the same thoughts, we probably could record thoughts with radio-electronic apparatus, without the need for the use of hands. This method would possibly also solve a very important practical problem, that of aiding the memory and the work of the human brain during the process of its varied creative activities.

It is now already possible to produce high speed scientific, technical, medical-diagnostic, and other electronic handbooks capable of greatly increasing mental productivity. This becomes more and more necessary, since the scope of human knowledge is continuously on the increase and to perceive it all it will obviously be necessary to resort to the use of technical means. In exactly the same manner, it is possible to automatize, with the aid of electronic digital computers, processes of administrative-economic control and even the control of military operations.[115,124,126]

In general, it is technically possible to produce an electronic machine for the performance of any complex function, which it can perform better than the man who has created this machine. However, the machine's ability will remain restricted to this function, it will remain an inorganic "amplifier of thinking."

However, the idea of creating an inorganic machine equivalent "in its capabilities" to the human brain in all the gamut of its creative activity, and capable of self-development during the process of this activity, is bound to be fruitless and unfounded. If one attempts to design a computing machine having the same number of memory elements as the human brain, even using the best electronic memory devices that the future may offer, its enormous size and power consumption will be found to be technically unrealizable.

CONCLUSION

Mention was made first of the difficulties of defining the scientific and technical scope of radio electronics, which is an all-embracing branch of modern knowledge. It is even more difficult to determine its future progress and practical applications, especially without touching indirectly upon various specific problems. Naturally, this holds also for any other large branch of science and technology.

However, it can be firmly stated that this future is rich and inexhaustible. Further advances in radio electronics and solutions to its new scientific and practical problems will serve the needs of further human progress and betterment.

---

[1] A. I. Berg, editor, Изобретение радио А. С. Поповым, (Invention of Radio by A. S. Popov), Collection of documents and materials. U.S.S.R. Acad. Sci. Press, 1945.

[2] A. A. Petrovskiĭ, Научные основания беспроволочной телеграфии (Scientific Fundamentals of Wireless Telegraphy), St. Petersburg, 1913.

[3] N. A. Nikitin, Нижегородская Радиолаборатория им. Ленина (The Lenin Nizhegorod Radio Laboratory), Sviaz'tekhizdat, 1954.

[4] M. A. Bonch-Bruevich, Сборник трудов (Collected Works), U.S.S.R. Acad. Sci. Press, 1956.

[5] A. D. Fortushenko, editor, 60 лет радио,

Научно-технический сборник (60 Years of Radio, Scientific-Technical Collection) Svyaz'izdat, 1955.

[6] Радиотехника и электроника (Radio Engineering and Electronics), No. 11, pp. 1319, 1344, 1360, 1375, 1390, 1413, 1435, 1451 (1957).

[7] B. A. Vvedenskiĭ and A. G. Arenberg, Long Distance Tropospheric Propagation of Ultrashort Waves Радиотехника (Radio Engineering), Nos. 1 and 2 (1957).

[8] G. P. Grudinskaya, Распространение УКВ (UHF Propagation), Gosenergoizdat, 1957.

[9] D. M. Vysokovskiĭ, Некоторые вопросы дальнего тропосферного распространения УКВ (Certain Problems in Long-Distance Tropospheric UHF Propagation), U.S.S.R. Acad. Sci. Press, 1958.

[10] G. H. Millman, Atmospheric Effects of VHF and UHF Propagation, Proc. IRE, **46**, No. 8, 1492 (1958).

[11] An Artificial Ionosphere, Brit. Comm. and Electronics **5**, No. 2, 117 (1958).

[12] K. I. Gringauz, Rocket Measurements of Electron Concentration in the Ionosphere. Dokl. Akad. Nauk SSSR **120**, 1234 (1958), Soviet Phys. "Doklady" **3**, 620 (1958).

[13] G. S. Kerblaĭ, Радиопрогнозы и их составление (Radio Forecasts and their Compilation), Svyaz'izdat, 1958.

[14] Ya. L. Al'pert, Certain Problems in the Physics of the Ionosphere. Usp. Fiz. Nauk **61**, 423 (1957).

[15] Electromagnetic Radiation in Nuclear Explosions and during Rocket Flight, Aviation Week **68**, No. 19, 26 (1958).

[16] Measurement of the Velocity of Light in Vacuo, Nature **181**, No. 4604, 258 (1958).

[17] Propagation of Radio Waves in a Layer of Snow. Новости зарубежной электроники, (News of Electronics Abroad), No. 4, 31 (1957).

[18] Park, David, Planar Transmission Lines, IRE Trans. Microwave Theory and Techn., No. 3–5, 1955.

[19] On the Spiral Waveguide, BSTJ **35**, No. 6, 1347 (1956).

[20] G. Z. Aĭzenberg, Антенны УКВ (UHF Antennas), Svyaz'izdat, 1957.

[21] R. C. Honey, E. M. T. Jones, Versatile Multipart Biconical Antenna, Proc. IRE, **45**, No. 10 1374 (1957).

[22] V. G. Myshkin, Electrodynamic Theory of Cylindrical Lunenberg Lenses, Изв. высш. учебн. завед. (радиофизика) (News of the Higher Inst. of Learning—Radiophysics), No. 1, 14 (1958).

[23] H. A. Wheeler, Fundamental Relations in the Design of a VHF Transmitting Antenna, Trans. IRE on Antenna and Propagation, B. AP-6, No. 1 120 (1958).

[24] W. I. Polydoroff, Magnetic Field Antenna, Electronics Industries **17**, No. 13, 66 (1958).

[25] F. Reggia et al., Designing Ferrite-Rod Antennas for X-Band Operation, Electronics **30**, No. 6, Buyers' Guide Issue 49 (1957).

[26] V. I. Talantov, Excitation of Surface Waves by the Open End of a Plane Waveguide, J. Tech. Phys. (U.S.S.R.) **28**, 1275 (1958), Soviet Phys. "Tech. Phys." **3**, 1185 (1958).

[27] B. Ancker-Johnson and J. J. Rowley, Mixed Garnets for Nonreciprocal Devices at Low Microwave Frequencies, Proc. IRE **46**, No. 7 1421 (1958).

[28] Round Table Discussion on Design Limitations of Microwaves, Trans. IRE on Microwave Theory and Techniques MTT-6, No. 1, 104 (1958).

[29] B. Lax, The Status of Microwave Applications of Ferrites and Semiconductors, Trans. IRE on Microwave Theory and Techniques MTT-6, No. 1, 5 (1958).

[30] Fox, Miller, and Weiss, Properties of Ferrites and their Application in the Microwave Band (Russ. Transl.), Soviet Radio Press, 1956.

[31] L. A. Mikaelyan, Некоторые применения ферритов в волновой технике (Certain Applications of Ferrites in Wave Techniques), Soviet Radio Press, 1958.

[32] A. A. Kosyrev et al., New Ferrites with Rectangular Hysteresis Loop, Радиоэлектроника (Radio Electronics) **18**, 22 (1957).

[33] I. A. Rajchman, Ferrite Apertured Plate for Random Access Memory, Proc. IRE **45**, No. 3, 325 (1957).

[34] C. F. Pulvari, Ferroelectrics and their Memory Applications, IRE Trans. on Comp. Parts. CP-2, No. 1 (1956).

[34a] V. M. Rodionov, Development of the Transmitting Radio Tube, Труды Ин-та Истории Естествознания и техники АН СССР (Trans. of Inst. of History of Natural Sciences and Engineering, U.S.S.R. Acad. Sci.) vol. 2, p. 72 (1957).

[35] M. S. Neĭman, Триодные и тетродные генераторы сверхвысоких частот (Triode and Tetrode Microwave Oscillators), Soviet Radio Press, 1950.

[36] V. F. Kovalenko, Введение в электронику сверхвысоких частот (Introduction to Microwave Electronics), Soviet Radio Press, 1950.

[37] E. D. Naumenko, (editor), Клистроны (Klystrons), Soviet Radio Press, 1952.

[38] V. T. Ovcharov (editor), Лампа с бегущей волной (The Traveling Wave Tube), Soviet Radio Press, 1952.

[39] R. G. Merimanov, Certain Problems in the Generation of Millimeter and Submillimeter Waves

Вестн. АН СССР (News of the U.S.S.R. Acad. Sci.) V, No. 6, 88 (1958).

[40] J. Holohan, New Trend of Microwave Tubes Spurs Radar, ECM, Scatter Designs, Aviation Age 29, No. 4, 22ff (1958).

[41] A. Van der Ziel, Fluctuations in Radio and Physics, (Russ. Transl.) Gosenergoizdat, 1958.

[42] E. B. Tucker and oth., The Resnatron as a 200-Mcs Power Amplifier, Proc. IRE **46**, No. 8 1483 (1958).

[43] H. D. Doolittle, The Design and Life of Planar Microwave Transmitting Tubes, Trans. IRE PG VC-4, 31 (1957).

[44] Electronic Industries **17**, No. 4, 2 (1958).

[45] Trans. IRE ED-4 No. 2, 161 (1957).

[46] W. C. Brown, Description and Operating Characteristics of The Platinotron—a New Microwave Device, Proc. IRE **45**, No. 9, 120 (1957).

[47] Signal **XI**, No. 5, 74 (1957).

[48] Proc. IRE **45**, No. 3, 141 (1957).

[49] Trans. IRE ED-4, No. 3, 246 (1957).

[49a] New UHF Vacuum Tube, Aviation Week **69**, No. 9, 64 (1958).

[49b] V. N. Shevchik, Основы электроники сверхвысоких частот (Fundamentals of Microwave Electronics) Soviet Radio Press, 1959.

[50] RCA Review **XVIII**, No. 3, 425 (1956).

[51] P. W. Kaseman, A New Image Orthicon Employing a Multi-alkali Photocathode for Color Cameras, Proc. of the National Electronics Conference **13**, Chicago, 1957.

[52] Electronics **29**, No. 11, 208 (1956).

[53] L. R. Bloom, Proc. National Electronics Conference **XIII**, 818 (1957).

[54] C. Du Four, Les Tubes cathodiques a Mémoire Electrostatique et leur Applications, Annales de Radioéléctricité XI, No. 45, 200 (1956).

[55] V. E. Straughan and E. F. Mayer, High Speed Printing of Cathode Ray Tube Information by Electrostatic Photography Techniques, Proc. of the National Electronics Conference **13**, Chicago (1957).

[56] Yu. M. Kushnir et al., Use of Electron-Optical Converter in Electron Microscope, Приборы и техника эксперимента (Instruments and Meas. Engg.) No. 3, **73** (1958).

[57] B. N. Popov and A. V. Druzhinin, High-Vacuum Emission Radio Microscope, Радиотехника электроники (Radio Engineering and Electronics) **3**, 1081, (1958).

[58] N. G. Basov and A. M. Prokhorov, On the Molecular Generator, Usp. Fiz. Nauk **57**, 485 (1955).

[59] A. Van der Ziel, Solid State Physical Electronics, Prentice-Hall, 1957.

[60] Symposium on the Role of Solid-State Phenomena in Electric Circuits, New York, 1957, Proc. Brooklyn, N. Y. 1957.

[61] M. P. G. Capelli, An Atomic Reference Oscillator, British Comm. and Electronics **5**, No. 2, 100 (1958).

[62] H. E. D. Scovil, The Three-Level Solid-State Maser, Trans. IRE on Microwave Theory and Techniques **I**, 29, (1958).

[63] J. W. Meyer, The Solid-State Maser-A Supercooled Amplifier, Electronics engineering edition, 66, 1958.

[64] F. R. Arams and G. Krayer, Design Considerations for Circulator Maser Systems, Proc. IRE **V**, 912 (1958).

[65] E. W. Herold, Future Circuits Aspects of Solid-State Phenomena, Proc. IRE **45**, No. 11, 1463 (1957).

[66] Low-Temperature Radio Electronics. Brit. Comm. and Electronics **5**, No. 4, 270 (1958).

[67] R. A. Chentsov, A Superconducting Amplifier —the Cryotron, Usp. Fiz. Nauk **64**, 193 (1958).

[68] V. M. Faĭn, Quantum Phenomena in the Radio Band, Usp. Fiz. Nauk **64**, 273 (1958).

[69] N. G. Basov and A. M. Prokhorov, Molecular Generators and Amplifers, Природа (Nature), No. 7, 24 (1958).

[70] S. Bloom and K. K. Chang, Parametric Amplification Using Low-Frequency Pumping, J. Appl. Phys. **29**, No. 3, 594 (1958).

[70a] British Comm. and Electronics **5**, No. 8, 612 (1958).

[71] Lo, Enders, et al., Transistor Electronics, N. Y., 1955 (Russ. Transl. Soviet Radio Press, 1958).

[72] I. G. Gurevich and I. M. Simkin, Кристаллический триод и его применение (The Transistor and its Applications) Belor. S.S.R. Acad. Sci. Press, Minsk, 1957.

[73] J. Stewart, Metal Power Rectifiers, Electroplating and Metal Finishing **9**, No. 7, 212 (1956).

[74] W. Wolfgang Gartner, Design Theory for Depletion Layer Transistors, Proc. IRE X, No. 10, 1392 (1957).

[75] H. Statz and R. A. Pucel, The Spacistor—a new class of highfrequency semiconductor Devices, Pros. IRE, No. 3, 317 (1957).

[76] The Gaussistor, a Semiconducting Device, Trans. IRE, ED-3, No. 3, 133 (1956).

[77] C. W. Mueller and J. Hilibrand, High-Speed Switching Thyristor, Trans. IRE on Devices, VED-5, No. 1, 2 (1958).

[78] Eg. Milh, Le Tecnêtron, triode solid pour hautes fréquences, Toute la Radio, No. 233, 47 (1958).

[79] The Transistor 1948 — 1958. Ten years of

progress..., Bell. Labor. Record **36**, No. 6 190 (1958).

[79a] Semiconductor Diode-Amplifier for the Centimeter Band, Bell. Lab. Record **36**, 250 (1958).

[80] Limman, Neue Halbleiter und ihre Schaltungen, Funkchau, No. 11, 283 (1958).

[80a] B. Kazan, An Improved High-Gain Panel Light Amplifier, Proc. IRE, No. 10, 1358 (1957).

[81] L. W. Stammerjohn, Magnetic Amplifiers: Basic Principles and Applications, Bell. Labor. Record **36**, No. 1, 16 (1958).

[82] Solion — electric converter, Brit. Comm. and Electronics **4**, No. 10, 617 (1957).

[83] Надежность наземного радиоэлектронного оборудования (Reliability of Electronic Surface Equipment), Soviet Radio Press, 1957.

[84] Problems of Reliability of Electronic Apparatus, Вопросы радиолокационной техники (Problems of Radar Electronics, No. 2, 38 (1957), and No. 5, 41 (1957).

[85] N. I. Kalashnikov, The Radio Relay System "Vesna" with Automatized Repeater Stations, Вестник связи (Communications Herald), No. 6, 3 (1958).

[86] Radio Communication by Reflection from Meteor Tracks, Proc. IRE **45**, No. 12, 1642 (1957).

[87] Microwave Communications, Electronics Engineering **30**, No. 363 (1958).

[88] V. I. Sardykov, Commercial Television Installations, Техника кино и телевидения (Motion Picture and Television Engineering) No. 8, 27 (1958).

[89] Flat Television Screens, Wireless World, 2—3, January, 1957.

[90] Stereoscopic Television Installation, Electronics and Radio Engineering, No. 5, 174 (1957).

[91] Радиолокационная техника (Radar Engineering), Soviet Radio Press, 1949.

[92] P. M. Woodward, Probability and Information Theory, with Applications to Radar, Pergamon Press, London. 1955 (Russ. Transl., Soviet Radio Press, 1955).

[93] Radar in Antiaircraft Defense, Interavia, No. 1, 55 (1956).

[93a] Radar Meets Space Challenge, Electronics **31**, No. 14, 14 (1958).

[94] System for Radar Detection of Rockets, British Comm. and Electronics, **5**, No. 4, 224 (1958).

[95] P. I. Yevdokimov et al. (edit.), Сбр Сборник по радиотелемеханике (Radiotelemechanics Anthology), Moscow, 1955.

[96] A. S. Locke, Principles of Guided Missile Design, N. Y. Van Nostrand, 1955 (Russ. Transl. Gostekhizdat 1957).

[97] G. J. Cassidy, Radio Doppler Measurements on the Russian Satellites at the National Standards Laboratory, Proc. IRE Australia **19**, No. 3, 105 (1958).

[98] P. A. Castruccio, Communications and Navigation Techniques of Interplanetary Travel, Trans. IRE ANE-4, No. 4, 216 (1957).

[99] H. E. Prew, Space Exploration—The New Challenge to the Electronics Industry, Trans. IRE, MIL 1, No. 2, 43 (1957).

[100] Application of Radar to Geodesy, Engineering, **203**, No. 5280, 538 (1957).

[101] F. W. Rupport, I. M. Smith, Airborne Weather Radar Uses Isoecho Circuit, Electronics **29**, No. 2, 147 (1956).

[102] Passive Radar, Вестник заро зарубежной радиоэлектроники (Herald of Electronics Abroad) **10**, 9 (1957).

[102a] New Radio Navigation System, Вопросы радиолокационной техники (Problems of Radar Engineering), No. 2 (1957).

[103] The TACAN System, Вопросы радиолокационной техники (Problems of Radar Engineering) No. 2 (1957).

[104] W. R. Principles and Performance Analysis of Doppler Navagation Systems, Trans. IRE on Aeronautical and Navigational Electronics ANE-4, 176 (1957).

[105] E. W. Anderson, Inertial Navigation Systems, J. Inst. Navig. **11**, No. 3, 231 (1958).

[106] I. S. Shklovskiĭ, Радиоастрономия (Radio Astronomy), Gostekhizdat, 1953.

[107] R. Hanbury Brown and A. C. B. Lovell, The Exploration of Space by Radio, London, 1958.

[108] On Radio Astronomy, Proc. IRE, 46, No. 1 (1958).

[109] I. S. Dzhigit and M. E. Zhabotinskii, Certain New Branches of Radio Electronics, Радиотехника (Radio Engineering) **12**, No. 10, 85 (1957).

[110] A. A. Manenkov and A. M. Prokhorov, Radiospectroscope for Observation of Electronic Paramagnetic Resonance, Радиотехника и электроника (Radio Engineering and Electrons) **1**, No. 4, 469 (1956).

[111] L. A. Artsimovich, Research on Controlled Thermonuclear Reactions in the U.S.S.R., Usp. Fiz. Nauk **66**, 545 (1958), Soviet Phys. "Uspekhi" **1**, 191 (1958).

[112] Direct Conversion of Nuclear Energy into Electricity, Military Review **36**, No. 6, 66 (1956).

[113] Direct Conversion of Thermal Energy into Electricity, RCA Review **19**, No. 2, 214 (1958).

[114] Ionic Rocket Project, Missiles and Rockets **2**, No. 6, 72 (1957).

[115] A. I. Kitov, Электронные цифровые машины (Electronic Digital Computers), Soviet Radio Press, 1956.

[116] C. E. Shannon and J. McCarthy (ed.), Automatic Machines, IL, 1956 (Russian Transl.).

[117] P. P. Kaĭzmer, Техническая кибернетика (Technical Cybernetics), Gosenergoizdat, 1958.

[118] N. Wiener, Cybernetics and Society (Russian Transl.) IIL, 1958.

[119] I. A. Poletaev, Сигнал (Signal), Soviet Radio Press, 1958.

[120] N. Wiener, Cybernetics, (Russ. Transl.) Soviet Radio Press, 1958.

[121] Voice-Controlled Machines, Bell. Labor. Record, No. 2, 281 (1957).

[122] L. L. Myasnikov, Говорящие, читающие и слушающие автоматы (Speaking, Reading, and Hearing Automata), Leningrad, 1957.

[123] Electronic Reading Automation, The Engineer. 203, No. 5277, 414 (1957).

[124] H. T. Rowe, The IBM Computer AN/FSQ-7 and the Electronic Air Defense System Sage, Computers and Automat 5, No. 9, 6—9, 12.

[125] Yu. D. Panov, Автоматический перевод (Automatic Translation), U.S.S.R. Acad. Sci. Press, 1956.

[126] On a Large Computing Machine, Elektronische Rundschau, No. 12, 340 (1956).

[127] Новости зарубежной радиоэлектроники (News of Electronics Abroad) No. 1, 1957.

[128] Вопросы радиолокационной техники (Problems of Radar Engineering) No. 2 (38), 1951.

[129] Aviation Week, No. 26, 62 (1957).

[130] Новости зарубежной радиоэлектроники (News of Electronics Abroad) No. 6 (1957).

Translated by J. G. Adashko