Scientific investigation, technological development and economical governmental support: the historical development of RADAR science and technology I[1]

Gorokhov V.G. (vitaly.gorokhov@mail.ru)

Institute for Philosophy of the Russian Academy of Sciences
Institute for Technology Assessment and System Analysis of the Forschungszentrum Karlsruhe

1. Methodological Analysis of the History of RADAR Science and Technology as a Scientific and Technological Discipline

The subject of methodological analysis in this article will be radar[2] science and technology as a special discipline of scientific engineering (as distinct from the engineering industry). This choice is predetermined by the following factors. Firstly, radar theory emerged in the framework of a developed engineering science, and one may speak of its independent evolution as an engineering discipline. It has branched off from another engineering science (radio engineering theory) and did not initially emerge as an applied natural science. And second, the invention of radar resulted in truly revolutionary changes in industrial radio production, as well as in the respective fields of engineering science and practical activity which, in turn, produced a powerful impulse back to radar, turning it, in the latter part of the 20th century, into a modern complex engineering discipline, namely, radar systems engineering. Radar theory is discussed in this article not as much as a specific engineering science, but as a model of development of an engineering discipline. On the one hand, it is an object of systems study; on the other, it has given an impetus in engineering science and activity to the development of methodological principles of the systems approach. In this sense, the invention of radar was a prerequisite for the development of systems engineering. As part of the “family” of systems engineering disciplines, it underwent radical transformations and arose as radar systems engineering. “The tremendous research and development effort that went into the development of radar and related techniques during World War II resulted not only in hundreds of radar sets for military (and some for possible peacetime) use but also in a great body of information and new techniques in the electronics and high-frequency fields. Because this basic material may be of great value to science and engineering, it seemed most important to publish it as soon as security permitted”. This work is the collective result of work done at many laboratories, Army, Navy, universities, and industrial in different countries. These results serve as a memorial to the unnamed hundreds and thousands of scientists, engineers, and others who actually carried on the research, development, and engineering work. “There were so many involved in this work and they worked so closely together even though often in widely separated laboratories that it is impossible to name or even to know those who contributed to a particular idea or development. Only certain can be mention”.[3] But to all those who contributed in any way to

---

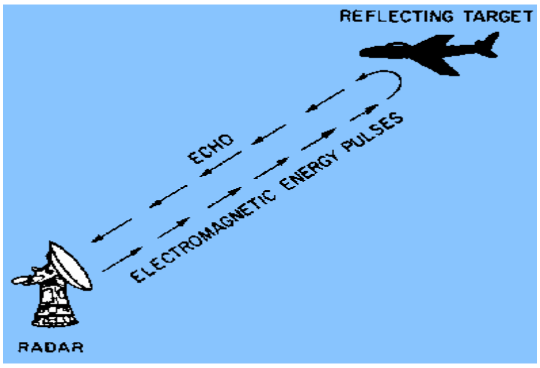
[1]This article has been prepared in the scope of RFFI-Project "The change of the paradigm of scientific and technological development in the context of the establishment of the global information society" 09-06-00042
[2] radar = Radio Detection and Ranging
[3] L.N. Ridenour (Ed.). Radar System Engineering. N.Y. and L.: McGraw- H ill Book Co., Inc., 1947, p. viii.

this great cooperative development enterprise – radar science and technology in England, Germany, USA, USSR, and in another countries these article are dedicated.

The base principle of the radar technology

“We do know several things, mainly from sociological and economic studies[4]. We know that novel technologies are shaped by social needs; that they issue often from experience gained outside the standard domain; that they originate more often in cultures that support risk; that they respond to economic incentives (to demand or to factor price changes); that they cumulate with the cumulation of scientific mediated by networks of colleagues. And we know, as the 1920s school emphasized, that novel technologies come into being as fresh combinations of existing ones—that, as Kaempffert put it, they are “composites of mechanical elements that accumulated as part of the social heritage”[5]. This combination idea is an old one; it goes back at least to Thurston writing in 1889,[6] recurs in Schumpeter in 1912, and becomes basic to the ideas of the 1920s. And it is certainly central to any theory of invention. But none of these early writers, nor any modern ones, explain satisfactorily how such combination takes place. The origin of technologies remains mysterious. …

A technology always proceeds from some central idea or concept — “the method of the thing.” … Thus the base principle (= the *base concept* or *base principle* of the technology – *V.G.)* of radar — the essential idea that allows it to work — is to send out high frequency radio waves and detect distant objects by analyzing the reflections of these signals from the objects’ surfaces. … That radio waves are reflected from metal objects is a phenomenon; the idea of using this to detect metal objects at a distance (in radar) constitutes a principle. A phenomenon is simply a natural effect, and as such it exists independently of humans and of technology; it has no “use” attached to it. A principle by contrast (as I will use the word) is the *idea of use of a phenomenon for some purpose*, and it exists very much in the world of humans and of use”.[7]



[4] See for example the work: Bijker, Wiebe. *Of Bicycles, Bakelite and Bulbs: Toward a Theory of Socio-technical Change*. MIT Press. Cambridge, Mass. 1995; David, Paul. *Technical Choice, Innovation, and Economic Growth*. Cambridge University Press, 1975; Dosi, Giovanni. “Sources, Procedures, and Microeconomic Effects of Innovation.” *Journal of Economic Literature*, XXVI, 1120-1171, Sep. 1988; Freeman, Christopher. *The Economics of Innovation.* Edward Elgar, Aldershot, England. 1990; Rosenberg, Nathan. *Inside the Black Box: Technology and Economics*. Cambridge Univ. Press. 1982.

[5] Quoted in: McGee, David. The Early Sociology of Invention. In: *Technology and Culture,* 36, 4, 1995, p. 782

[6] Thurston, Robert. *A History of the Growth of the Steam Engine*. 1889 [Assoc. Faculty Pr Inc. 1971], pp. 2-3

[7] A.W. Brian. The Logic of Invention. Santa Fe Institute and PARC. December 19, 2005. - http://www.santafe.edu/research/publications/workingpapers/05-12-045.pdf; A.W. Brian. The Structure of Technology. 2006 http://www.santafe.edu/~wbarthur/documents/Invention-Arthur.pdf

Fig. 1[8]

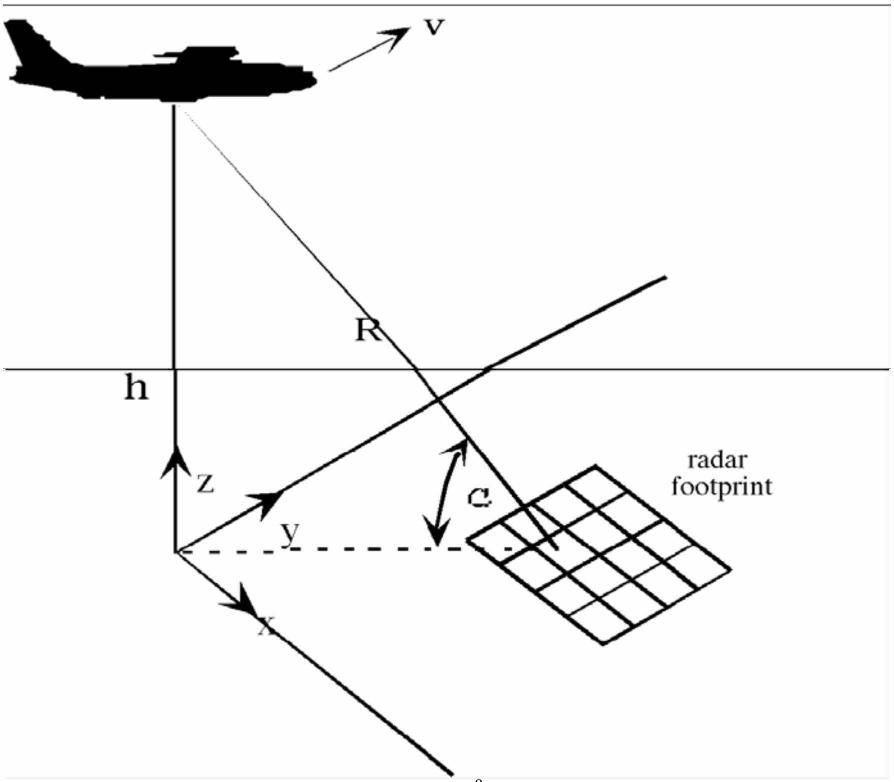


Fig. 2[9]

Footprint - the area illuminated by the radar

"To understand a technology means to understand its principle and how this translates into a working architecture".[10]

In this article I want to look in detail at the process by which radically novel science and technology – radar science and technology – originate. I will speak of the origination of sciences and technologies an example of one of them – radar science and technology – rather than separate inventions, discoveries and innovations. My interest is not only to add fresh detail to the stories of this particular sphere of science and technology but rather to use this example as case study to uncover the social and logical structure of the origination of new sciences and technologies at all. I am going in this article not only to investigate the external social conditions of the origination of radar R & D and industrial organizational structures (first of all in the Soviet Union) but also to analyze of the internal methodological structures of the radar science and technology as a new scientific-technological discipline and technological theory.

Two basic phases in the development of radar theory can be distinguished. The first is associated with the gradual evolution of one of the branches of radio engineering into a new engineering discipline; and the second is connected with the "revolutionary" transition to a radically new systems and cybernetics view of the world [systems ontology], replacing the traditional electrodynamic of the radio-engineering with a switchover to qualitatively new activity settings, norms of scientific thinking, and working methods.

---

[8] See: Radarentwicklung. Die technischen Grundlagen des Radar. - radarstrahlung.de

[9] See: W. Wiesbeck. Lecture Script "Radar System Engineering". 13th Edition WS 2006/2007. Institut für Höchstfrequenztechnik und Elektronik, Universität Karlsruhe: www.ihe.uni-karlsruhe.de

[10] Arthur W. Brian. The Logic of Invention. Santa Fe Institute and PARC. December 19, 2005.

Now, let us see how this initial structure of radio engineering theory evolved in the process of its formation and the development of its new research trend — radar theory, then radically transformed into a modern discipline — radar systems engineering. We shall trace these changes against the background of the following dynamic parameters of scientific disciplines: a growing number of publications, a changing structure of the body of publications and of the research community (establishment of institutes, departments, magazines, etc.). Important for studies of engineering sciences are also data on the development of industrial facilities and engineering activity. Against the background of these dynamic parameters (which provide reference and targeting points for methodological systems analysis of the history of science) one can much better see the internal structural changes in an engineering theory as well.

A Modern Scientific-Technological Disciplines

The sphere of scientific-technological disciplines, which are intensively elaborated today, along with the natural-scientific, mathematical, social disciplines and humanities, incorporates a great number of the most varied fields of research, engineering, and design. They have at present or are founding disciplinary organizations (a specific range of publications and a limited research community), and now have a stable position in science. In addition, as shown above, by the second half of the 20th century, a majority of the scientific-technological disciplines had begun their own theoretical studies, which have received the status of a technical theory.

There are two basic methods for the development of ‘classical’ technical sciences: first, from the new applied research directions of any natural-scientific theory; and second, they may ‘bud out’ from a corresponding, basic technical theory within the framework of a ‘family’ of homogeneous scientific-technological disciplines which have recently emerged, and which are oriented on use in the engineering practice and design not only of natural sciences, but for social sciences and the humanities as well. The range of design tasks has also been enlarged, and now includes the problems of social and economic, engineering and psychological, systems and other aspects. Finally, there appeared such scientific-technical disciplines, which are the result of complicated interdisciplinary processes taking place in the technical sciences. Such scientific-technological disciplines may be referred to as the modern complex of (‘non-classical’) scientific-technological disciplines. Among them are, for example, systems engineering, ergonomics, systems design, informatics, operations research, and so on. The present complex scientific-technological disciplines represent a reality of contemporary science. However, they do not fit into the traditional forms of organization or methodological standards. It is precisely the sphere of these investigations and disciplines where an ‘internal’ interaction of social, natural, and technical sciences is being realized today. These sciences also summarize research and design (R&D) orientations and form a single R&D-establishment (for complex research and system designing) in the process of solving complex scientific and technical problems and tasks. The corresponding investigations, for example, in the field of artificial intelligence, require a special management support and search for new forms of scientific organization (for instance, in temporary scientific teams and problem groups).

2. Development of a New Research Trend in Radio Engineering

According to Soviet and foreign sources, radar was invented at roughly the same time in various countries (the USSR, the USA, Great Britain and Germany) as a response to a clear public order for the creation of new types of radio engineering instruments — radars or radio-locating systems (RLS). Engineers and scientists were confronted with a definite engineering challenge: to investigate the possible use of radio waves for locating various objects and to develop the respective devices.[11]

[11] See: R. Burns (Ed.). RADAR Development to 1945. London: Peter Peregrinus Ltd., 1988; U. Kern. Die Entstehung der Radarverfahren: zur Geschichte der Radartechnik bis 1945. Stuttgart: Abteilung Geschichte der Naturwissenschaft und Technik, 1984; u.a.

However, solving this task called for a series of new research efforts, and for that reason, complex scientific problems were formulated, and, in addressing them, a new direction of research in radio engineering evolved. “Translating a principle into a workable technology is indeed a new phase, whether the principle has been arrived at by seeing the possibilities of a phenomenon or by pondering the requirements of some need. The process must now be taken from mental concept to physical embodiment, and this gives it a more physical character. Solutions that were conceptual must be produced in physical form, and subproblems that were partially bypassed must be dealt with directly. … It falls into two overlapping phases: the search for a principle (or the suggestion of one from a phenomenon or effect); and the translation of this into physical reality”.[12]

At this stage of the new discipline’s development based on modified theoretical radio engineering as applied to new functions of new types of radio engineering devices were gradually taking shape. Radar is not yet regarded as a variety of radio engineering devices functioning by impulses and at ultrahigh frequencies.

By the early 1930’s, two basic methods of measuring distance by means of radio waves were known, namely, the pulse- and the phase-metrical methods. The first method was used to sound the upper atmospheric layers (the ionosphere, or the so-called fifth Heaviside layer).[13] In 1932-1933, it was specially studied for purposes of location by means of radio waves. The second method, which is sometimes called the interferential or “beat” method, was based on the Doppler effect[14]; it was designed to measure distance through changes in the frequencies of waves transmitted and received. “When we designate a novel technology as an “invention,” we find always a purpose carried out by a new or different base principle. Consider: In the 1930s approaching aircraft could be detected over the horizon by listening for acoustic emissions. Radar was based on a different principle: picking up the faint echoes that aircraft reflected from radio pulses”.[15]

---

[12] A.W. Brian. The Logic of Invention. Santa Fe Institute and PARC. December 19, 2005.

[13] “The principle of pulse ranging which characterizes modern radar was first used in 1925 by Breit and Tuve, of the Carnegie Institution of Washington, for measuring the height of the ionosphere. After the successful experiments of Breit and Tuve, the radio-pulse echo technique became the established method for ionospheric investigation in all countries”. See: M.A. Tuve and G. Breit. “Terrestrial Magnetism and Atmospheric Electricity,” Vol. 30, March-December 1925, pp. 15—16. Also *Phys Rev*, 28, 554, 1926. (L.N. Ridenour (Ed.). Radar System Engineering. N.Y. and L.: McGraw- H ill Book Co., Inc., 1947, p. 13).

[14] “The Doppler effect was first explained by an Austrian scientist named Christian Doppler in 1842. He used the changing the sound of train passing on a railroad track. Doppler effect in a nutshell is that the speed of the particle is determined by its frequency shift. As a particle is approaching a radar beam its radiation wave is compressed into higher wave frequency due to its progressive motion towards the radar. A particle moving away from a the radar beam will experience a lengthening of the wave which has a lower wave frequency. The Doppler radar uses this theory to determine motion and direction of the wind speed” (Basic Radar Theory. - http://snrs.unl.edu/amet451/marsh/theory.html).

[15] Arthur W. Brian. The Logic of Invention. Santa Fe Institute and PARC. December 19, 2005

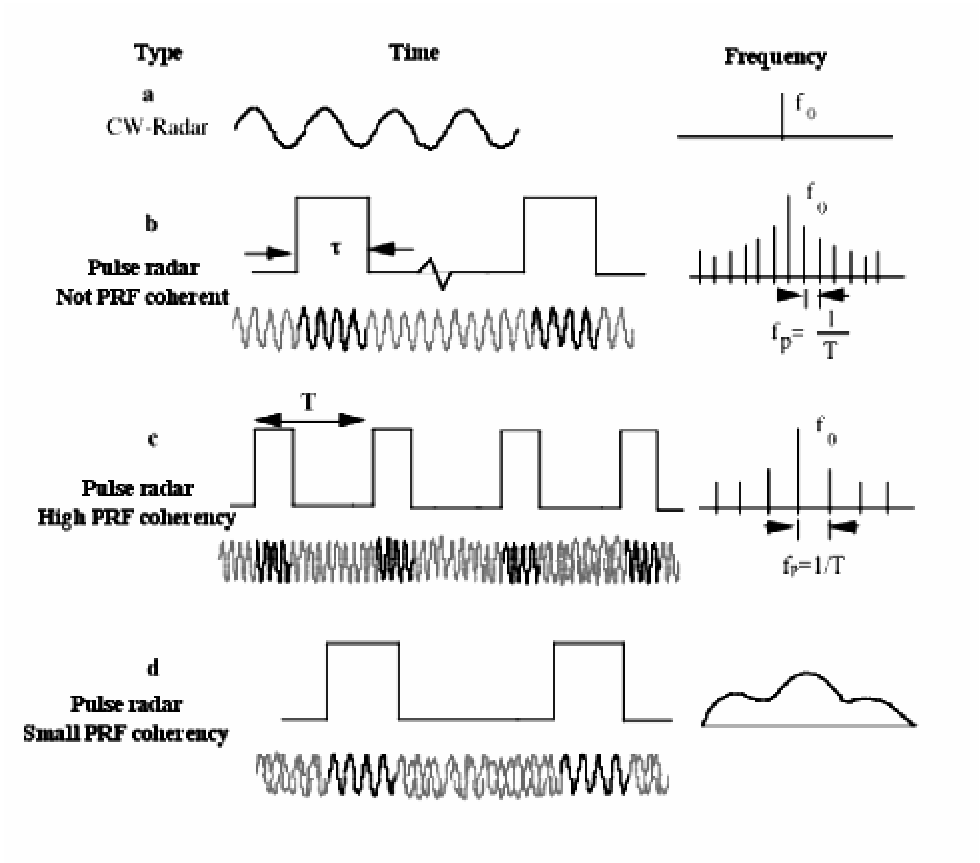


Fig. 3

«Pulse radar instruments can, in principle, be divided into four categories, of which however, not all are suitable for each application. The subdivision takes places once after the existence of the phase preservation between the transmitting and receiving signal according to»: Coherent radar (phase preservation), Incoherent radar (arbitrary phase from pulse to pulse); as well according to the pulse repetition frequency (PRF): Low PRF (< 1000 Hz), High PRF (> 30000 Hz). "The first pulse radars had a very low pulse repetition rate. On one side, one could not create a higher pulse rate and on the other side, one could not process it. After the Second World War the pulse repetition rate could be incrementally increased as much as the demanded, unique range of coverage permitted. The until today valid fundamentals of pulse radar technology had been laid down by Colonel Blair of the US Signal Corps in a patent from 1938". CW Radar is continuous wave radar. [16]

The choice initially fell on the second method (interference technique), although later, the pulse technique proved to be more efficient. The choice of the second method was preconditioned, in the first place, by the fact that the developers of the earliest radar equipment were guided by traditional radio engineering concepts — the older paradigm in these scientific and engineering disciplines (the new one was just beginning to emerge). Initially, it seemed that the phase-metering method neither required any new equipment (a decimeter wave transmitter was already in use) nor intricate theoretical research.[17]

But as work proceeded, many technical difficulties turned up; the consistent efforts to overcome them led to the development of radically new engineering and scientific solutions.

[16] W. Wiesbeck. Lecture Script "Radar System Engineering". 13th Edition WS 2006/2007. Institut für Höchstfrequenztechnik und Elektronik, Universität Karlsruhe: www.ihe.uni-karlsruhe.de

[17] "A change in principle, then, fits with our intuition of what constitutes a novel technology. I will therefore define a new (radically novel) technology as one that achieves a purpose by using a new or different base principle than used before" (Arthur W. Brian. The Logic of Invention. Santa Fe Institute and PARC. December 19, 2005).

First of all, a transition to shorter wavelengths was required, in order to improve the performance of radar devices, which, in turn, posed the problem of developing ultrahigh frequency (UHF) transmitters. For this reason, the development of radar facilities was primarily an effort to improve individual locating devices (oscillators[18], receivers, amplifiers, antennas, etc.). They had to be invented, designed, scientifically tested and manufactured (devices such as chamber magnetrons, various klystrons with disc terminals for decimeter waves, traveling-wave tubes, waveguides, etc.). "A radar set can be considered as separable, for the purposes of design and description, into several major components concerned with different functions" (see **Fig. 4**).[19]

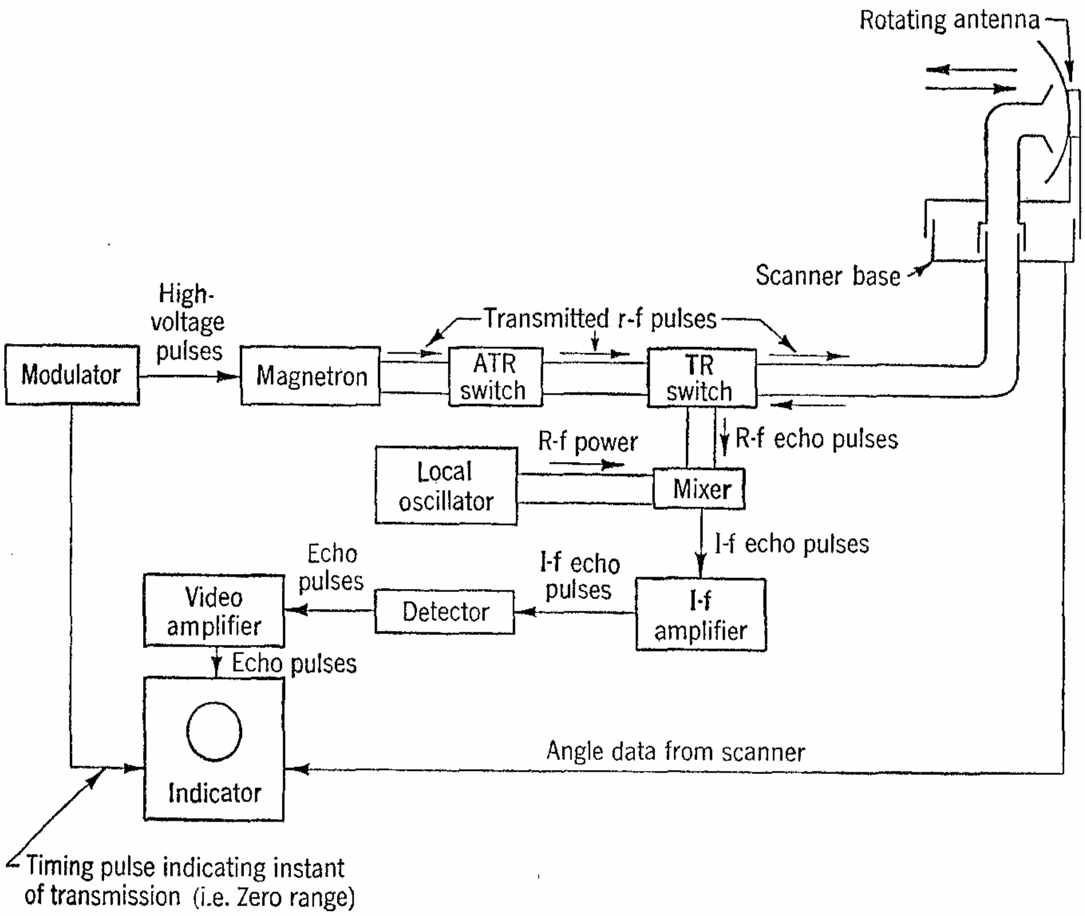


Fig. 4. Block diagram of a simple radar set[20]

[18] For example, oscillator "generates the high-frequency oscillations at the high power required. It is switched on by the rising or leading edge of the d.c. pulse from the modulator and is switched off by the falling or trailing edge of the pulse. Thus the transmitter produces a pulse of r.f. energy at the frequency of the oscillator. … to produce the very high frequencies at the high powers needed by centimetric radars the oscillator uses special microwave devices (e.g. magnetrons or klystrons). Note also that although the pulse duration may be very short the frequency is sufficiently high to ensure that each pulse contains a large number of cycles of radio frequency" (Radar Theory. - http://www.radarpages.co.uk/theory/ap3302/sec1/reqpmr/reqpmr23.htm).

[19] L.N. Ridenour (Ed.). Radar System Engineering. N.Y. and L.: McGraw- H ill Book Co., Inc., 1947, p. 6

[20] In the set illustrated in Fig. 4, "a cycle of operation is begun by the firing of the modulator. This sends a high-power, high-voltage pulse to the magnetron, which is the type of transmitting tube almost universally used in modern radar. For the brief duration of the modulator pulse ... the magnetron oscillates at the radio frequency for which it is designed ... The r-f pulse thus produced travels down the r-f transmission line shown by double lines …, and passes through the two switches designated as TR and ATR. These are gas-discharge devices of a very special sort. The gas discharge is started by the high-power r-f pulse from the transmitter, and maintained for the duration of that pulse; during this time the TR (for transmit-receive) switch connects the transmitter r-f line to the antenna, and disconnects the mixer and the rest of the radar receiver shown below the TR switch. The ATR (for anti-TR) switch, when fired, simply permits the r-f pulse from the transmitter to pass through it with negligible loss. Between pulses, when these gas-discharge switches are in an unfired state, the TR switch

The transition to ultrahigh frequencies necessitated intensive research into this new field of new radio engineering devices. The developers had to face challenges either unknown in radio engineering or held to be secondary. One of' these problems was to suppress external interference and internal noise[21] in receiving waves reflected from the “target”, since the chief function of a radar is to measure accurately the parameters of the reflected wave, in order to determine the nature of the “target”. Solving these problems required enormous efforts and ingenuity on the part of the designers, and they developed special devices for reducing interference and noise.

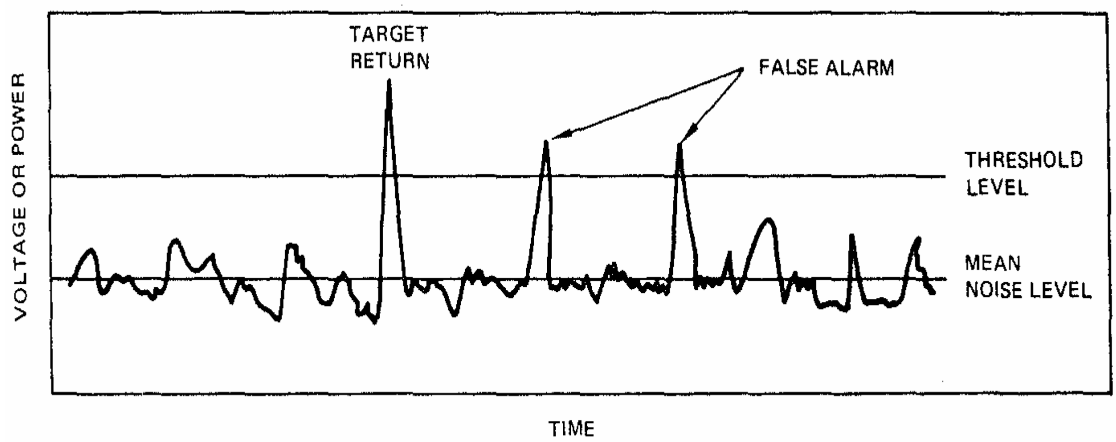


Fig. 5. Radar receiver output as a function of time

However, a truly dramatic change in the traditional concepts of radar devices was brought about by the use of the pulse method, which superceded the usual concepts, and had important advantages: it markedly increased radar’s capacity, made it possible to locate several

---

connects the mixer to the antenna, and the ATR disconnects the magnetron to prevent loss of any part of the feeble received signal. After passing through these two switches, the transmitter pulse travels down the r-f line to the antenna, where it is radiated. The antenna is designed in such a way that the beam shape it produces is suitable for the requirements the radar set must meet. It is mounted on a scanner which is arranged to sweep the beam through space in the manner desired … After the transmission of the pulse, the discharges in the TR and ATR switches cease and the system is ready to receive echoes. Echoes are picked up by the antenna and sent down the r-f line to the mixer. The mixer is a nonlinear device which, in addition to receiving the signals from the antenna, is supplied c-w power from a local oscillator operating at a frequency only a few tens of megacycles per second away from the magnetron frequency. The difference frequency that results from mixing these two signals contains the same intelligence as did the original r-f echoes, but it is at a sufficiently low frequency … to be amplified by more or less conventional techniques in the intermediate-frequency amplifier shown. Output signals from the i-f amplifier are demodulated by a detector, arid the resulting unipolar signals are further amplified by a video-frequency amplifier ... The output signals of the video amplifier are passed to the indicator, which displays them … in plan-position form. In order to do this, it must receive a timing pulse from the modulator, to indicate the instant at which each of the uniform range sweeps out from the center of the PPI tube should begin. It must also receive from the scanner information on the direction in which the antenna is pointing, in order that the range sweep be executed in the proper direction from the center of the tube” (L.N. Ridenour (Ed.). Radar System Engineering. N.Y. and L.: McGraw- H ill Book Co., Inc., 1947, p. 7, 8).

[21] “In the detection circuitry of the radar, this target return power is processed in the presence of receiver noise”. **Fig. 5** “gives a qualitative description of target detection in the presence of receiver noise. A threshold is set so as to result in an acceptable number of false alarms (threshold crossings due to noise) per given time, for example, five per minute. Increasing the threshold level will, of course, decrease the number of false alarms, but it will also decrease target detection capability. Thus, the setting thresholds is a trade-off between the desired false alarm rate and the detection capability. … Receiver noise can originate within the receiver itself or it may enter the receiver through the receiving antenna. One portion of the noise generated within the receiver is due to the thermal agitation of electrons in the receiver” (S.A. Hovanessian. Radar system design and analysis. Dedham: ARTECH HOUSE, INC., 1984).

"targets", and to use a single transmitting and receiving antenna, etc. And although the same principle of transmitting electromagnetic energy over a distance was used, it was different methods of their representation from those of radio engineering. Other parameters of electromagnetic waves (the length and on-off relation, ratio of the pulse, the configuration of' its front, and the frequency of repetition, etc.) were also becoming more significant (**Fig. 6**).[22] In radio engineering, the parameters of electromagnetic oscillations help to "decipher" a text, whereas in radar location, the pulse parameters help determine the nature and coordinates of "targets" visually registered (and not bearing them) on devices of a radically new type, i.e., cathode ray tubes.

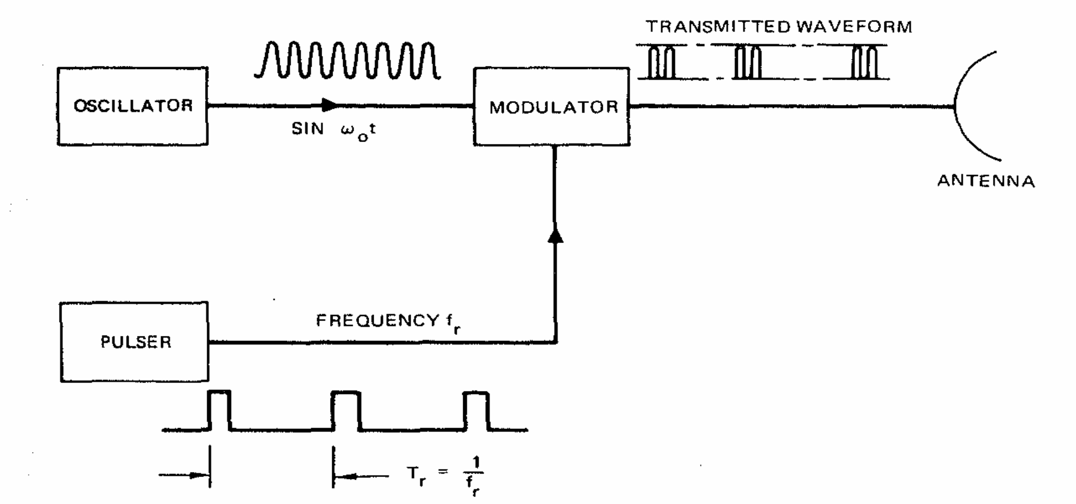


Fig. 6. Radar transmission of a pulse form

Furthermore, as the operation of this new type of radio engineering devices changed, there was a gradual change in radar design. Initially, it was intended to design and construct them as separate receivers and transmitters; later, when a common antenna came into use, other structure of radar systems were developed, as well as new units not used in traditional radio engineering devices such as the duplexer, the synchronizer and the radarscope (indicator or display equipment). New pulse devices were developed (blocking oscillators, multivibrators[23], pulse amplifier, threshold element etc.) as well as methods of analyzing and synthesis. New

---

[22] "The term "target" is applied to any reflecting object which interferes with the transmitted wave and reflects part of its energy. … It will be seen that a comparison of the properties of the transmitted energy with that of the reflected energy from a target will result in parameters relating the relative radar-target positions. The frequency shift between transmitted and reflected wave is proportional to radar-target closing rate and the delay between transmitted and received electromagnetic energy is proportional to the distance between the radar and the target. … The transmitter consists primarily of an oscillator generating electromagnetic energy at a certain frequency. Part of this energy is intercepted by the target and reflected. A comparison of the properties of transmitted radar energy with energy reflected from the target will result in such in formation as the total transmitter-target-receiver distance … and the rate of decrease (closing rate) of these quantities". … In the radar transmitter (**Fig. 6**) generates the oscillator on the left of the figure "the sine wave with angular frequency $\acute{\omega}_{o.}$ The pulser generates the train of rectangular pulses which are fed to the modulating amplifier. The transmitted signal then takes the form of a pulsed sine wave as shown" (S.A. Hovanessian. Radar system design and analysis. Dedham: ARTECH HOUSE, INC., 1984).

[23] For example, "monostable multivibrators are circuits with one stable state. They remain in the stable state until triggered, when they then 'flip' over to the other state. They remain in the unstable state for a time decided by the circuit constants and then, of their own accord, 'flop' back to the original stable state. Flip-flops find many applications in radar. They may be used to generate rectangular pulses 'locked' to precise time intervals, to reshape pulse trains which have deteriorated in shape, to stretch narrow pulses into wider ones or to generate a time delay. … The flip-flop produces a rectangular wave whose leading edge is coincident in time with the trigger pulse and whose trailing edge may be varied with time" (see: Radar Theory. - http://www.radarpages.co.uk/theory/ap3302/sec2/ch2/sec2ch272.htm).

elements called for new methods of their representation in the theory.[24] But we can also say "that technologies proceed from phenomena, and phenomena present themselves in natural clusters bringing a train of technologies in their wake. As electricity comes to be understood between 1800 and 1875, a constellation of phenomena presents itself: capacitance, induction, deflection of charges by electric and magnetic fields, glow discharge, and electromagnetic radiation. These bring a train of technologies that includes capacitors and inductors, transformers, telegraphy, the electrical generator and motor, the telephone, wireless telegraphy, the cathode ray tube, the vacuum tube, and modern radio, television, radar, electron microscopy and computers. Similarly, as quantum understandings grow in the twentieth century, the laser, transistor, integrated circuit, magnetic resonance imaging, high-temperature superconductor, carbon nanotube, and other technologies based on these emerge. … We can therefore say that, viewed in the large, radically novel technologies emerge both from the cumulation of existing building-block technologies and from understandings of the phenomena that surround these".[25]

*Origination**:** scientific investigation and invention – experiment tests and first public demonstrations – foundation of the companies – first patents*

"The new phase normally will have been already partially under way. Some components of the device or method may have been constructed in experiments, and physical trials of the base concept in action may have been attempted. But even with such early results in hand, challenges still arise. Envisaged subtechnology solutions may not work, or may press upon performance limits. … Indeed, the most important contribution of the British radar effort lay not in envisioning of the principle of radar. That had been seen by many in the scientific community before.22 It lay in solving a critical sub-problem, that of finding a means for producing high-powered microwave signals, by originating a component technology—the cavity magnetron".[26]

"On the *30th April 1904*, Christian Huelsmeyer in Duesseldorf, Germany, applied for a patent for his 'telemobiloscope' which was a transmitter-receiver system for detecting distant metallic objects by means of electrical waves. … He … founded the company 'Telemobiloscop-Gesellschaft Huelsmeyer und Mannheim'. The first public demonstration of his 'telemobiloscope' took place on the 18th May 1904 at the Hohenzollern Bridge, Cologne. As a ship on the river approached, one could hear a bell ringing. The ringing ceased only when the ship changed direction and left the beam of his 'telemobiloscope'. All tests carried out gave positive results. The press and public opinion were very favorable. However, neither the naval authorities nor industry showed interest. … He received a fourth patent on the 11th November 1904 in England. … A description in English on how his radar system worked is detailed in his US patent 810,150 dated Jan. 16, 1906".[27]

"In 1921 Albert W. Hull at General Electric Co. investigated the motion of electrons in a cylindrical diode under the influence of a homogeneous axial magnetic field. He noticed the possibility to control the electron current to the anode by variation of the magnetic field. Hull wanted to develop for his company a magnetically controlled relay or amplifier in competition to the grid controlled triodes of

[24] "Scientists who originate need to be, at least in some organ of their being, engineers. And engineers who originate need to be in no small part theoretical scientists" (A.W. Brian. The Logic of Invention. Santa Fe Institute and PARC. December 19, 2005).

[25] A.W. Brian. The Logic of Invention. Santa Fe Institute and PARC. December 19, 2005, p. 14-15.

[26] "As early as 1904, a German engineer, Christian Hülsmeyer, had taken out patents on a device for preventing collisions at sea, using radio waves, and by the 1930s several practitioners, Marconi among them, had experimented with primitive radio detection devices. See Ch. Süsskind ("Who Invented radar?" In: Burns (ed.). RADAR Development to 1945. London: Peter Peregrinus Ltd., 1988, p. 506-12) and ("Radar as a Study in Simultaneous Invention." In: Blumtritt, Petzold, and Aspray, eds. *Tracking the History of Radar*, 237-45. IEEE, Piscataway, New Jersey. 1994)". (A.W. Brian. The Logic of Invention. Santa Fe Institute and PARC. December 19, 2005, p. 9).

[27] Christian Huelsmeyer, the inventor. In: Radar World **-** http://www.radarworld.org/huelsmeyer.html

Western Electric Co., but also noted the possibility of RF generation. He called his novel device "magnetron". … Hans Erich Hollmann filed in Germany on November 27, 1935, a patent on the multi-cavity magnetron. US Patent 2,123,728 was granted on July 12, 1938 …, well ahead of J. Randall's and H. Boot's work in February 1940. The operation principle of a reflex klystron was anticipated by Hollmann as early as 1929 who patented a "double-grid retarding-field tube".[28]

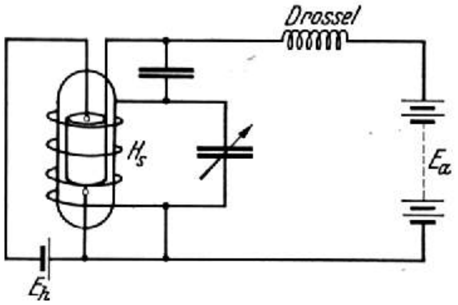


Fig. 7
Schematic of the classic magnetron transmitter by Hull[29]

Industry showed interest — designing radar as a single prototype and as a market product – interest by the military — invention of the new components und their patents — first publications

"Although the first ideas of using radio beams for guiding aircraft go back as far as 1904, the practical use of such systems did not take place until 1932 with the German Lorenz A.G. Companies instrument landing system which was proposed and developed by the "father of instrument landing," Dr. E. Kramar. At that time, instrument landing systems and navigation systems were called "Bordfunkgeraete" in Germany. Translated this simply means "onboard radio devices" … In 1937 the Lorenz Company set about improving the marker beacons with the first patents filed by Dr. Kramar who designed a ground transmitter with two antennas located one above the other. The antennas could be sequentially operated such that two vertical beams were produced with one beam below the 3 degree approach path. This beam would give the pilot the lower limit of his approach path. This idea was reinvented and employed in the USA in 1940"**.**[30]

"The first practical radar system was produced in 1935 by the British physicist Sir Robert Watson-Watt, and by 1939 England had established a chain of radar stations along its south and east coasts to detect aggressors in the air or on the sea"**.**[31] Robert Watson-Watt was then at the head of the Radio Department of the National Physical Laboratory. "During the winter of 1934-1935, the Air Ministry set up a Committee for the Scientific Survey of Air Defense. … The first experimental radar system of the type suggested by Watson-Watt was set up in the late spring of 1935 on a small island off the east coast of England. Development work during the summer led to the blocking-out of the main features of the British Home Chain of early-warning stations ... Work began in 1936 toward setting up five stations ... By March 1938, all these stations — the nucleus of the final Chain — were complete and in operation under the charge of RAF personnel".[32]

"After the First World War, military aircraft improved rapidly in range and speed, and by the early 1930s Britain became acutely aware of its vulnerability to attack from the air. The menace became the

---

[28] M. Thumm. Historical German contributions to physics and applications of electromagnetic oscillations and waves. - http://www.radarworld.org/history.pdf. "Many "inventions" are in reality improvements on earlier embodiments of a known idea. Randal and Boot are credited with the invention of the cavity magnetron, but in actuality a decade's worth of experimentation and theorizing on "split-anode" magnetrons had preceded their device. Indeed Hans Hollman in Germany had been granted a US patent on a cavity magnetron two years before Randall and Boot's work" (A.W. Brian. The Logic of Invention. Santa Fe Institute and PARC. December 19, 2005).
[29] See: Radar Development In England. - http://www.radarworld.org/england2.html
[30] History of radio flight navigation systems. - http://www.radarworld.org/flightnav.pdf
[31] Alfred Lee Loomis. - http://www.ob-ultrasound.net/loomis.html
[32] L.N. Ridenour (Ed.). Radar System Engineering. N.Y. and L.: McGraw- H ill Book Co., Inc., 1947, p. 14.

subject of political and public debate. “That there is at present no means of preventing enemy bombers from depositing their loads of explosives, incendiary materials, gases, or bacteria upon their objectives I believe to be true”, wrote Frederick Lindemann to the *Times* in 1934. The British Air Ministry took notice and considered different principles to respond to the problem.[33] Among these, and by no means the most promising at the beginning, was the idea of detecting aircraft by reflected radio waves—what was subsequently called radar”.[34]

„In early 1939, a radar set designed and built at the Naval Research Laboratory was given exhaustive tests at sea during battle maneuvers, installed on the U.S.S. New York. The first contract for the commercial manufacture of radar equipment was let as a result of these tests, for the construction of six sets … In November 1938, a radar position-finding equipment intended for the control of antiaircraft guns and searchlights, designed and built by the Signal Corps Laboratories of the Army, was given extensive tests by the Coast Artillery Board, representing the using arm. This set also went into quantity manufacture, as the SCR-268 … An Army long-range aircraft-detection set whose development had been requested earlier by the Air Corps was demonstrated to the Secretary of War by the Signal Corps Laboratories in November 1939. A contract for the production of this equipment, the SCR-270 (and SCR-271 …) was let in August 1940”.[35]

“Above, Dr. Hans Eric Hollmann is consulting for the GEMA Company where he helped design the first modern radar sets. He had over 300 patents to his name. 76 of these patents were filed in the US by the Telefunken Company for which he consulted. Telefunken built the Wuerzburg radar sets which used most of H. E. Hollmann's inventions. Working in his company "Laboratory for High Frequency and Electromedicine," which employed 20 scientists, Hollmann developed the high frequency technology which led to the development of radar. … In 1935, H. E. Hollmann wrote the first comprehensive books on microwaves. The books are titled "Physics and Technique of Ultrashort Waves." The books were used in all countries of the world and it fueled the development of radar in all of the major countries in the world. His book showed examples of applications of microwaves”**.**[36]

The First Radars in Russia[37]

“In 1932, Pavel Oshchepkov, an engineer from an antiaircraft artillery regiment stationed in Pskov, suggested a new method of detecting aeroplanes. … In 1934, the detection of aircraft by means of radars was for the first time included in the research plans of the Guidance, Early Warning Detection, and Communications Service of the USSR’s Air Defence. In 1936, the radar division became part of the Red Army’s Communications Research Institute. … On January 11, 1934, The Chief Artillery Directorate of the Red Army entered into an agreement with the Leningrad Institute of Electrophysics for designing radars to detect aeroplanes and guide searchlights so as to provide antiaircraft artillery with visible targets. The “Rapid” prototype radar using 25 cm radio waves was built at the institute between 1934 and 1935. *The prototype radar was successfully tested* on June 10 and 11, 1934. … In 1935, the principal components of the “Electrovisor” constant emission-reception radar system were made at the Leningrad Komintern plant on orders from the Directorate for Air Defence. At the same time, the “Model-2” system was created in cooperation with the Leningrad Institute of Physics and Technology where, on April 1, an *antiaircraft radar laboratory* opened. Then, all research centred on the impulse method. … Project Director was Dmitry Rozhansky who died in September 1936 and was replaced by Yuri Kobzarev, a prominent scientist. Although the work progressed successfully, the Directorate for Air Defence of the Red Army made no plans to complete the development of the “Rapid”, “Electrovisor”, “Model-2” and some other systems. All financing was cut and the research stopped in late 1930s. In 1937, the development of the “Reven” microwave radar began in Moscow at

---

[33] Buderi, Robert. *The Invention that Changed the World*. Simon and Schuster, New York. 1996, p. 53.
[34] Arthur W. Brian. The Logic of Invention. Santa Fe Institute and PARC. December 19, 2005.
[35] L.N. Ridenour (Ed.). Radar System Engineering. N.Y. and L.: McGraw- H ill Book Co., Inc., 1947, p. 14.
[36] Dr. Hans E. Hollmann, the Physicist and "Father of Modern Radar and Microwave Technology". Copyright 2001 Martin Hollmann. In: Radar World - http://www.radarworld.org/hollmann.html
[37] Mikhail Pervov. FROM "BERKUT" TO "TRIUMF. - http://www.aviarus-21.com/index-eng.htm; see also: Advanced radar techniques and systems. Ed. by G. Galati. London: Peter Peregrinus Ltd., 1993

the army Institute for Communications Research. The design had been commissioned by the Guidance, Detection, Early Warning and Communications Service of the Air Defence. Two prototypes were made and successfully tested in 1938. On orders from … the People's Commissar of Defence, the "Reven" system, which by then had been code-indexed RUS-1, was adopted by the Red Army. The Second Air Defence Corps used it during the war with Finland. The radar could detect the presence of aeroplanes and sent signals when they crossed the line of observation, yet couldn't guide intercepting fighters. The experimental "Redoubt" long-range radar was designed jointly by the research teams of the Leningrad Institute of Physics and Technology headed by Yuri Kobzarev and the army Institute for Communications Research. The first "Redoubts" were made at the Leningrad Research Institute of Radio Industry. … The Project Director was A. B. Slepushkin. On June 26, 1940 … the army replaced the truck-based RUS-1 systems with the RUS-2s. The new radar's detection range was up to 150 km, depending on the height of incoming planes. It showed distance to target and could guide fighters. It also could detect single aeroplanes. A total of 10 such radars were made … In May, 1940, the team of researchers and designers of the Leningrad Institute of Physics and Technology began developing a new radar system for the Guidance, Early Warning, Detection, and Communications Service. The new radar was supposed to use just one rotating antenna instead of a rotating cabin and a synchronisation system controlling two pivoting antennas. This would simplify manufacturing and make the radar more reliable. …Exactly a year later, in May 1941, a sample RUS-2 single-antenna station was ready to be tested by the client service. The radar came in transportable crates and could be set up in the field or in a village house. A month later, its RUS-2s version was adopted by the Air Defence under the code name of "Pegmatit". … However, the mass production of the "Pegmatit" radars soon began ... Moscow's research institutions continued modifying these radars until 1945. … In 1942, mass production underway, the large-scale use of the radars at the front lines began. First, RUS-1 radars detected the presence of incoming enemy planes. … The war continuing, the number of radars produced for the Guidance, Early Warning, Detection, and Communications Service kept growing. … The RUS radars of all modifications were used in the air defences of Moscow, Stalingrad, and Gorky …The use of radars allowed saving ammunition considerably while the accuracy of fire grew just as greatly. …However, the further growth of radar-related research and production required new governmental decisions and sizable investments of money and labour".

Since that time, radiolocation has been a separate field of study. New theoretical representations had been developed in sufficient detail; as yet, however, they were only a particular variety of more general radio engineering concepts.

3. Radiolocation as a Field of Study

The qualitatively new field of radar using ultrahigh frequencies and pulse modulation stimulated the emergence of new elements and systems. The development of radar pulse techniques and technology, in turn, presupposed study of the laws governing the propagation of deci- and centimeter waves and changing pulse processes, as well as the development of methods of calculating, analyzing and synthesis new circuits. At this stage, a new field of research gradually developed in radiolocation — radar. "Radar is also recognized as the field of science and technology that includes the methods and equipment to perform the following basic operations against the targets of interest: (1) Radar detection, (2) Radar measurement, (3) Radar recognition, discrimination, and identification … The term radar is applied to applications for solving scientific and practical problems in different branches of human activity. For example, one refers to subsurface radar, radar astronomy, geographic research radar".[38]

Three layers of coordinated schematic diagrams can be distinguished in radiolocation which may be designated provisionally as "electrical engineering", as radio engineering and as

[38] D.K. Barton, S.A. Leonov (Eds.). Radar Technology Encyclopedia (Electronic Edition). Boston, London: Artech House, 1998. ISBN 0-89006-893-3

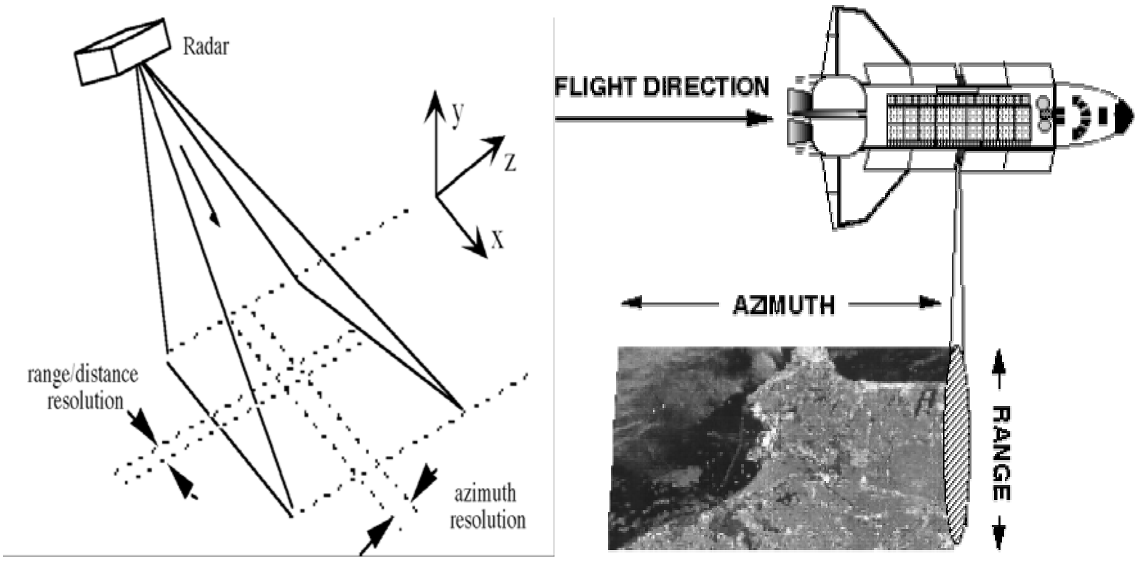
radiolocation proper. In radio engineering, only the first two layers are in existence. The "electrical engineering" schematic diagrams reflect physical processes which take place within the elements and units of radio engineering and radio locating devices. Such diagrams deal with the calculation of parameters and the mapping of electric currents in standard electrical elements such as resistors, capacitors, and inductors.

Of course, these devices can be called electrical circuit only with reservations. Use is made of electronics theory to describe the physical processes in the new radio engineering elements such as, for example, electron tubes or semiconductor devices. But to calculate of the parameters of these devices in which they are included use is, as a rule, made of traditional equivalent circuit (resistors, capacitors and inductors). As the physical processes in elements of radiolocating devices (klystrons, magnetrons, cathode ray tubes, antennas, etc.) operating in new radio engineering regimes are different, it was necessary to modify the former methods of their calculation and representation or to develop new ones, as well as to develop new mathematical resources. The process was also stimulated by the need to investigate and develop methods of internal noise suppression in elements of radiolocation equipment (for example, the schrot effect in electron tubes).

The widespread use of radar also led to the transformation of traditional radio engineering representations, primarily by expanding the practical wavebands. Study of the laws of propagation of ultrahigh-frequency bands and superhigh-frequency bands of electromagnetic oscillations stimulated by radiolocation made it possible to find new aspects of the electrodynamics world of view [theory] on which radio engineering is based. As it is essential for radiolocation to take account of the noise and interference in the environment, the working definition of the latter as empty space was no longer adequate to the tasks tackled in radiolocation. It was necessary to take the impact of the environment on the propagation of radio waves into account: for instance, such phenomena as refraction (deflection from a straight path of radio waves), dispersion (dependence of phase velocity on frequency), absorption or scattering of waves in varying media, etc. The need to find and identify "targets" by the nature of their influence on radio waves stimulated research into the scattering properties of various objects — mirror reflection, diffuse scattering, secondary resonance emission — which resulted in the emergence of new concepts, methods of graphic representation of process data and their mathematical description. The development of the pulse technology also exerted considerable influence on the formation of new concepts about pulse processes, their propagation in the environment and the techniques of forming, amplifying and analyzing radar systems with pulse radiation.

The creation of radar systems was associated with the development and systematization of various methods of detecting "targets" and plotting their coordinates. Because it was necessary in the first place to locate moving "targets" on a map, many ideas and terms in radiolocation were drawn from geodesy, cartography and navigation (**Fig. 8**). "A typical radar (Radio Detection and Ranging) measures the strength and round-trip time of the microwave signals that are emitted by a radar antenna and reflected off a distant surface or object. The radar antenna alternately transmits and receives pulses at particular microwave wavelengths … and polarizations (waves polarized in a single vertical or horizontal plane)."[39]

[39] T. Freeman. What *is* Imaging Radar? - http://southport.jpl.nasa.gov/desc/imagingradarv3.html



a) b)

Fig. 8[40]

There were the representations of directed beams of varying forms (for example, the multilobed beam) and methods of scanning (target tracking), the basic location-finding techniques, etc. Special concepts of surface and positional lines, pinpoint and extended targets, coordinates (distance, azimuth and angle of location), the target's flight path and radial speed, effective scattering area, sighting mark, the radar's resolution (distance and angular coordinates), precision bearing reading, scanning sector and boundaries, the beam's space angle, etc., are introduced. The main function of radiolocation theory is to identify representations on a radarscope as real objects against the background of locality, to distinguish the "targets" and to measure their parameters. For this purpose special radarscope and antennas are developed (in the first place, to obtain a definite form of the beam and image on the display and various techniques of establishing and calculating the target's coordinates (the minimum and maximum methods, the method of equal signals, etc.).

An important task for radiolocation was a special study of measurement errors, the interference that cause them, and the methods of eliminating them. Various types of mathematical methods were developed to solve such tasks.

As radiolocation developed into a field of study, efforts were made to develop the first prototypes of industrial radars. Awareness of a common structure for various radars grew. They may have varying designs and forms, but they are all based on the same principles. At the same time, radars are recognized to be a special type of engineering apparatus qualitatively different from other types of radio engineering devices (the term "radiolocation" becomes common in 1941[41]). The specifications of this object were determined first, by the changing functions of old blocks and the invention of new ones, and second, by a different mode of operation.

In radar, new blocks were installed which hadn't existed in earlier radio-engineering systems. To fulfill its basic function of locating a target and the measurment of its coordinates by the

---

[40] Fig. 8 a) is from: W. Wiesbeck. Lecture Script "Radar System Engineering". 13th Edition WS 2006/2007. Institut für Höchstfrequenztechnik und Elektronik, Universität Karlsruhe: www.ihe.uni-karlsruhe.de; Fig. 8 b) is from: T. Freeman. What *is* Imaging Radar? - http://southport.jpl.nasa.gov/desc/imagingradarv3.html

[41] Radar. An official history of a new science with technical descriptions and glossary of radar terms. Britisch information services. An agency of the British government. Printed in USA, 1945, p. 16

operator — a radar had to have various radarscopes (primarily cathode-ray tubes) which entailed the development of various technical facilities and adjustments to process the pulse reflected from the "target" or continuous electromagnetic oscillation, as well as special elements and devices to suppress interference.

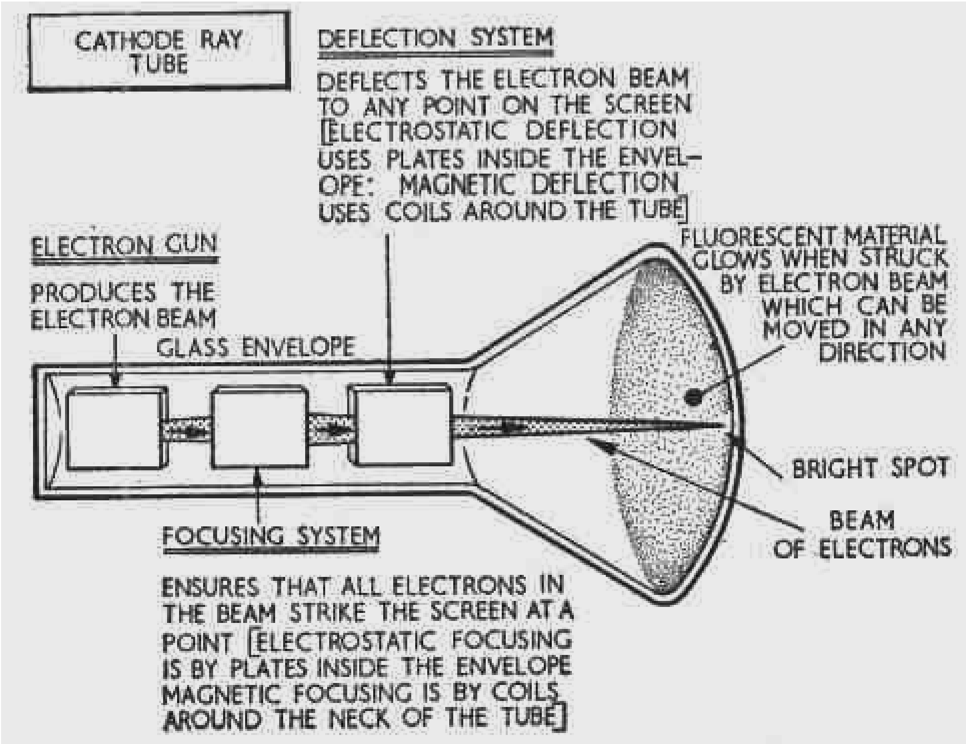


Fig. 9[42]

The complexity of control and the need for synchronous operation of all of the radar's components called for the development of a special synchronizer device. An essential component of any receiver or transmitter is an antenna. In radiolocation, paramount importance is attached to antennas which are very sophisticated and refined devices. Special efforts are required to calculate and design an antenna switch (in stereoscopic aerials), the mechanical and electromechanical units to move the antenna, the reflecting mirrors, various types of emitters, etc.

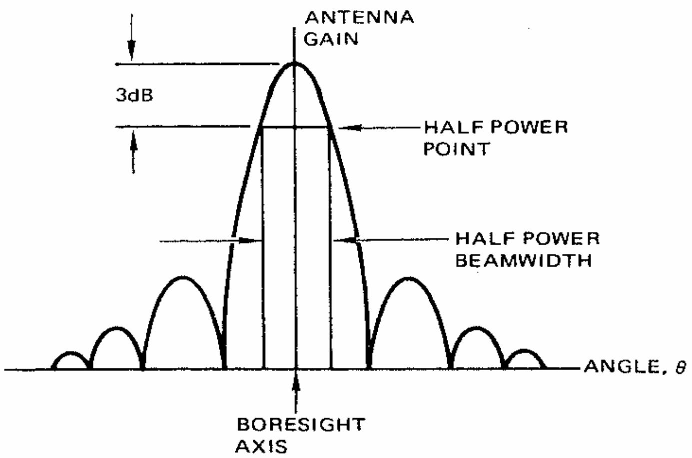


Fig. 10. Typical antenna gain curves[43]

[42] Radar Theory. - http://www.radarpages.co.uk/theory/ap3302/sec1/reqpmr/reqpmr23.htm
[43] S.A. Hovanessian. Radar system design and analysis. Dedham: ARTECH HOUSE, Inc., 1984, p. 5

Serial and mass production of an engineering product of a given type (in our case, radar) is very important for the progress of engineering discipline and engineering theory.

During the period under review, the production of various types of radar and their widespread use began.[44] Such production is directly connected with the development and improvement of technological equipment for radar; work to develop new technological devices such as, for example, metal-ceramic tubes, and to improve the quality of radar's components was in progress.

The rapid growth of industry and mass production[45] stimulated the standardization of equipment and circuits´ solutions, as well as technical documentation, leading to the formation of a new and uniform ideal that facilitated the theoretical analysis and synthesis of various engineering systems by typical methods and means — the ideal radar system.[46]

The development of radiolocation is a new field of study within the framework of radio engineering, and can also be characterized as follows: When radiolocation was emerging as a field of research, problems were dealt with only by individual, isolated groups of scientists and laboratories. During the period treated here, the number of radar researchers and developers grew rapidly. Earlier radar research and design (R & D) was typically pursued by scattered groups of engineers in different countries, relatively isolated from one another. As the number of such groups grew larger, it became necessary to coordinate their research and its results.

Military use – organisation of serial production – scientific research and design – industrial and basic research institutions – the organisation of the engineering and scientific education

"In WWII radar was able to find and locate the enemy and navigation systems existed that allowed aircraft to operate over friendly and enemy territory without visual aids over long range. This development took place at a breath taking speed from the Ultra High Frequency, UHF to the centimeter wave length. The decisive advantage and superiority for the Air Force or the Navy depended on who had the better radar and UHF technology"**.**[47]

The Microwave Committee of the National Defense Research Committee (NDRC) decided to set up a development laboratory staffed primarily by physicists from a number of universities. "Microwave Committee persuaded the Massachusetts Institute of Technology to accept the responsibility of administering the new laboratory. The Radiation Laboratory, as it was named, opened its doors early in November 1940. The director of the laboratory throughout its 62 months of life was Dr. L.A. DuBridge. The Army and Navy development laboratories were glad to depend on the new Radiation

---

[44] "The uses made of radar were so various under wartime conditions that many different systems were developed to fill different needs. These systems usually differed more in regard to beam shape, scanning means, and mode of indication than in regard to any other properties" (L.N. Ridenour (Ed.). Radar System Engineering. N.Y. and L.: McGraw- H ill Book Co., Inc., 1947, p. 12).

[45] "The growth of the radar industry, which scarcely existed before 1940, is indicated by the fact that by the end of June 1945, approximately $2,700,000,000 worth of radar equipment had been delivered to the Army and the Navy. At the end of the war, radar equipment was being produced at a rate of more than $100,000,000 worth per mouth" (L.N. Ridenour (Ed.). Radar System Engineering. N.Y. and L.: McGraw- H ill Book Co., Inc., 1947, p. 17). See also: Radar. A report of science at war released by the joint board on scientific information policy for: office of scientific research and development, war department, navy department. 1945; Radar Development in America. In: Radar World - http://www.radarworld.org/america.html; Radar Development in England. In: Radar World - http://www.radarworld.org/england2.html; Radar Development in Germany. In: Radar World - http://www.radarworld.org/germany.html

[46] D. Barton. Radar System Analysis. N.J., Prentice Hall, Inc. Englewood Cliffs, 1964, p. 156

[47] Gerhard Hepcke. THE RADAR WAR. Translated into English by Hannah Liebmann, p. 1

Laboratory for an investigation of the usefulness for radar of the new microwave region of the radio spectrum. They were fully occupied with the urgent engineering, training, and installation problems involved in getting radar equipment that had already been developed out into actual military and naval service. At the end of 1940, the use of microwaves for radar purposes seemed highly speculative, and the Service laboratories quite properly felt it their duty to concentrate on radar techniques that had already been worked out successfully".[48]

At the start of the war a large number of their projects were directed toward military use. For example: The production of radars for airplanes begins in England in 1939. "The MIT Radiation Laboratory, operated on this site between 1940 and 1945, advanced the allied war effort by making fundamental contributions to the design and deployment of microwave radar systems"**.**[49] **"**Before the end of 1940, the work on radar of American and British laboratories had been combined as a result of an agreement between the two governments for exchange of technical information of a military nature. A British Technical Mission arrived in Washington in September 1940 and mutual disclosures were made of British and American accomplishments in radar up to that time. Members of the British mission visited the Naval Research Laboratory, the Army Signal Corps Laboratories at Fort Monmouth, and the Aircraft Radio Laboratory at Wright Field, as well as manufacturing establishments engaged in radar work. They demonstrated their version of the cavity magnetron and furnished design information that enabled U.S. manufacturers to duplicate it promptly".[50]

The Radiation Laboratory of MIT, which operated under the supervision of the National Defense Research Committee, was approved and finances provided by the Office of Scientific Research and Development (OSRD). OSRD "was an agency of the United States federal government created to coordinate scientific research for military purposes during World War II". OSRD was created in Mai/Juni 1941 and discontinued in December 1947. "It superseded the work of the National Defense Research Committee (NDRC), was given almost unlimited access to funding and resources, and was run by Vannevar Bush, who reported only to President Franklin Delano Roosevelt".[51]

«Despite Germany's large technical lead at the beginning of the war, the English and the US caught up with Germanys radar technology in about 1942 by employing huge amounts of resources. The MIT Radiation Laboratory alone spent over $2 billion over the five years during the war. Only the development of the atom bomb during WWII could rival by cost an approximately equal amount»**.**[52]

The Council on Radiolocation in Russia

"On July 4, 1943, just one day before the great battle near the city of Kursk began, Joseph Stalin, Chairman of the State Committee for Defence, signed the directive "On the Organisation of the Production of Radars". The term used in the directive for radar detection was "radiolocation". So it became far more widespread after Stalin used it while the term "radar detection" was gradually forgotten. The directive for Stalin to sign had been written by Prof. Axel Berg[53]. … In his directive,

---

[48] L.N. Ridenour (Ed.). Radar System Engineering. N.Y. and L.: McGraw- H ill Book Co., Inc., 1947, p. 16
[49] Robert Hanbury Brown 1916 – 2002. Radar Personalities. – http://www.radarpages.co.uk/people/hanbury_brown/hanbury_brown.htm
[50] L.N. Ridenour (Ed.). Radar System Engineering. N.Y. and L.: McGraw- H ill Book Co., Inc., 1947, p. 15
[51] http://en.wikipedia.org/wiki/Office_of_Scientific_Research_and_Development
[52] Gerhard Hepcke. THE RADAR WAR. Translated into English by Hannah Liebmann, p. 52
[53] "The most brilliant figure in the history of domestic radio engineering was Radar Council Deputy Chairman Aksel Ivanovich Berg. He was a top-level scientist (see his book: A.I. Berg. *General Theory of Radio Engineering.* Leningrad, 1925 – *V.G.*), military chief, and bold government official combined in one person. … At that time (1943 - *V.G.*), Berg occupied the post of Deputy People's Commissar of the Electrical Industry. He was also Malenkov's deputy on the Radar Council, and … he had been selected as a corresponding member of the Academy of Sciences (later also as fool member). Rather than an elderly professor, it was a seaman with the rank of Vice Admiral … His unusual biography became available to the scientific community ... Aksel Berg's father was a Swede and his mother an Italian. … During World War I, the 22-year-old Berg was a submarine navigator, becoming a submarine commander after the Revolution. Following the civil war, Berg graduated from the Naval Academy, stayed on there as a radio engineering instructor, and attained the academic title of professor

Stalin ordered the creation of the Council on Radiolocation under the State Defence Committee. Soon, the All-Union Radiolocation Institute, the All-Union Electro-vacuum Institute, and the Central Design Bureau were established. … The Council on Radiolocation and the head research institute … On November 25, 1943, on orders from the Council of People's Commissars, the laboratory headed by Yuri Kobzarev was transferred from the Leningrad Institute of Physics and Technology … It was soon joined by the Central Design Bureau, which was supposed to work on the application of radars, and by the New Technologies Bureau of the 5th Chief Directorate of the Ministry of Defence. … As soon as the organisational problems had been resolved, the Council on Radiolocation went to work creating a radar industry in the USSR".[54]

Yuri B. Kobzarev
(1905-1992)

Project Director of the radar system "Model-2" in the Leningrad Institute of Physics and Technology – in 1936; 1943-1946 - member of the Council for Radiolocation; Organizer and head of the chairs of radiolocation in the Moscow Energetic Technological University (MEI),1950 - 1960 - head of the department of the radiolocation in the Scientific Institute for Radar Research [NII-20], from 1970 - member of the Russian Academy of Sciences

Fig. 12[55]

In the USSR in 1943 was organized the Research Institute for Radiolocation underfoot of the Council of Radiolocation of the State Defensive Committee, which was reorganized in the Committee of Radiolocation in 1947, together with Scientific-Technological Council in 1945 and Information Centre in 1946.[56] 1944 were established the chairs of radiolocation in the Moscow Energetic Technological University (MEI) and in the Moscow Aviation Technological University (MAI).

4. Radiolocation as an independent scientific and engineering discipline

---

and the military rank of captain first class. … Berg, who had developed methods for calculating the reliability of systems that contained a large number of elements, even got involved in debates with our chief designers" (Chertok B.E. Rockets and People: Creating a Rocket Industry (Volume II) / by Boris E.(NASA History Series). Washington, DC: NASA History Division, Office of External Relations, 2006, p. 3).

[54] Mikhail Pervov. FROM "BERKUT" TO "TRIUMF. - http://www.aviarus-21.com/index-eng.htm. "Admiral (and Academician) was the deputy President of the Council, the creation of which brought the term radar – radiolokatsiya – into official Soviet usage, in place of the earlier designation radioobnaruzhenie (radio detection). In the beginning the Council had four departments – scientific, industrial, military, and scientific-technical information, but expanded steadily" (J. Erickson. The air defence problem and the Soviet rdar programme 1934/35-1945. In: R. Burns (Ed.). RADAR Development to 1945. London: Peter Peregrinus Ltd., 1988, p. 234).

[55] See: Kobzarev Juriy Borisovich (1905-1992) - http://www.mpei.ru/lang/rus/main/aboutuniversity/science/scienceschools/radioeng/kobzarevjub.asp

[56] "There was now a centralised and unified approach to the radar programme, embracing not only research and development but also production, with Soviet industry towards the end of the war producing on average 44 RUS-l sets, 12 RUS-2 sets, 132 truck-mounted single antenna RUS-2 units, 120 SON-2ot GE radars, 231 GNEIS-2/GNEIS-2M airborne sets and 24 GNEIS-5/ GNEIS-5M sets" (J. Erickson. The air defence problem and the Soviet radar programme 1934/35-1945. In: R. Burns (Ed.). RADAR Development to 1945. London: Peter Peregrinus Ltd., 1988, p. 234).

By the late fifties, a whole family of engineering disciplines had been established, oriented towards the electrodynamic theory; they had branched off from basic engineering science, and followed the unique pattern of this science. “In the early fifties the term “radio electronics” won general recognition ...”. Radio electronics include a complex of varied knowledge stemming from radio engineering and electronics, namely, radiocommunication of all types, such as radio broadcasting, television, radio navigation, infrared signalling, radio astronomy, radio meteorology, radiospectroscopy, radiotelemechanics, industrial electronics, electronic computers, electrovacuum technology, semiconductor technology, etc.[57] Radiolocation arose as a new scientific discipline within the framework of radioelectronics.

The most important achievement at the given stage in the development of radar theory was the compilation of a corresponding mathematical apparatus specifically for radiolocation, i.e., statistical radiolocation. The need for a radar theory establishing the basic laws and quality criteria for any radar system led to the development of a probabilistic approach to the solution of its problems to serve as a basis for developing new methods of signals processing and design. The point is that noise discrimination, which had become central in radiolocation, is, by its nature, a statistical problem, and can be solved only by methods of the probability theory. Signal reception is thus regarded as a statistical problem first in radiolocation and then in radio engineering. Target criteria were formulated in radar theory and the properties of targets began to be described by statistical methods. Radar theory “summarizing the relationships which can be used to develop mathematical descriptions of typical radar targets”.[58] This is a direct application of probability theory to the problem of deciding which of a set of possible targets. “The reliability of discrimination depends on the noise level, the background hash, the variation of echo with target aspect angles, the energy and shape of the transmitted pulse, and the number of pulses. The effect of each of these variables is calculated and discussed, leading to some new conclusions about optimal radar design and optimal data processing”.[59]

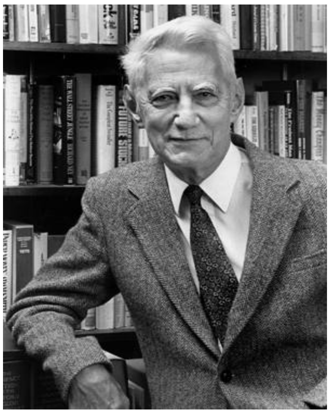
[57] Mintz A.L. Radiotekhnika, radiofizika, radioelektronika [Radio engineering, radio physics, electronics]. In: Izvestija vuzov: radionfizika [The transactions of higher educational institutions: radiophysics], 1974, vol. 18, No. 5, pp. 645-646

[58] D. Barton. Radar System Analysis. Prentice-Hall, 1964, p. viii.

[59] “If radar systems could distinguish different targets from each other, there would be big advantages in air safety. Airport traffic controllers have made serious errors from their inability to determine which echo on their screen represents which flight. … Presumably, good target discrimination would be helpful also in radar weather forecasting; and the same principles will apply as well in ultrasound imaging for medical diagnosis. But although the technical problem of target discrimination has been well recognized and studied for many years, no good solutions have been forthcoming. With recent renewed emphasis on the importance of the problem, it appeared that better understanding of the theoretical problem is a prerequisite for any practical hardware improvements. Past efforts have tended to consider the problem as one of physics (electromagnetic/acoustic scattering theory, etc.). But although the physics is well understood, this alone has not led to progress. More fundamentally, it is a problem of information processing, calling for a full application of probability theory. There have been few past efforts to use probability theory, and they have been based on “sampling theory" methods which are unable to deal with nuisance parameters such as aspect angle, or to make use of all the supplementary information available to a radar operator or system” (E.T. Jaynes. Theory of radar target discrimination).

There were the important scientific contributions of Shanon[60] in USA and Kotelnikov[61] in USSR. "No country´s governmental science is any "freer" than any other`s, not are secret scientific choices. … Listening to American and Soviet scientists, trying to study the way in which you both do your government science, I am struck, not by the differences but by the similarities. If there is any difference, it is perhaps that, because of the special privileges and autonomy of the Soviet Academy, Russian scientists take a slightly loftier attitude: and also, though this may be a superficial impression, I fancy their major choices involve more scientific minds, are slightly more broadly based, than with you or us".[62]

Claude Shannon
(1916-2001)
Father of Information Theory



Shannon joined the mathematics department at Bell Laboratories in 1941 and remained affiliated with the Labs until 1972. He became a visiting professor at MIT in 1956, a permanent member of the faculty in 1958, and a professor emeritus in 1978.

a)

Vladimir A. Kotelnikov
(1908 - 2005)
«Over the years the West had its Shannon; and the East had its Kotelnikov» (President EEEE)

Professor of the Moscow Energy Technological University, Vice-President of the Russian Academy of Sciences, director of the Institute for radio technology and electronics at the Russian Academy of Science

b)

Fig. 13[63]

Thus, by this time two interrelated theoretical representations had developed in radar theory — the representations reflecting respectively electrodynamic processes and their statistical models. For example, the so-called Rayleigh target, is, on the one hand, a mathematical-statistical object (that classifies various "targets") which is adequate to a certain type of probability distribution (that of the Rayleigh distribution): and, on the other hand, it has a clear electrodynamic correlate. "... the target may be described physically as a single large

60 "In 1948 Shannon published his landmark *A Mathematical Theory of Communication*. He begins this pioneering paper on information theory by observing that "the fundamental problem of communication is that of reproducing at one point either exactly or approximately a message selected at another point." He then proceeds to so thoroughly establish the foundations of information theory that his framework and terminology remain standard. Shannon's theory was an immediate success with communications engineers and stimulated the technology which led to today's Information Age. … Another example is Shannon's 1949 paper entitled *Communication Theory of Secrecy Systems*. This work is now generally credited with transforming cryptography from an art to a science." (Claude Shannon. Father of Information Theory. - http://www.bell-labs.com/news/2001/february/26/1.html). See also: J.J. O'Connor and E.F. Robertson Claude Elwood Shannon. - http://www-groups.dcs.st-and.ac.uk/~history/Mathematicians/Shannon.html.

61 Vladimir A. Kotelnikov is a creator of the theory of potential noise-immunity (Kotel'nikov V.A. The Theory of Optimum Noise Immunity. McGraw-Hill Book Co., 1959).

62 C.P. Snow. Science and Government. Cambridge, Massachusetts: Harvard University Press, 1961, p. 55.

63 **Fig. 13** a) is from: http://www.bell-labs.com/news/2001/february/26/1.html; Fig. 13 b) is from: Ju.V.Gulyaev. Kratkaja nauchnaja biografia akademika V.A. Kotelnikova. - http://www.cplire.ru/koi/Kotelnikov/index.html

reflector combined with other, smaller objects which produce constructive and destructive inference with the main source. The Rayleigh target, on the other hand, is assumed to be composed of a large number of reflecting elements of comparable size ...“.[64] The mathematical models of errors and noises are calculated in the same way. For example, “normal noise” is used as basic interference model by virtue of its simple mathematical description.

In the period treated here, radar theory developed procedures of analysis and synthesis of the theoretical representations of radar systems. The task of analyzing the operational properties of various specific radar systems boils down to a study of the intricate processes of their functioning under the impact of a signal mixed with noise and interference.[65]

The methods used in radiolocation make it possible to compare radars differing in type, specifications, and design (airborne, onboard, ground, search, target and missile tracking, precision approach, fire control, etc.) according to the same criteria. With this aim in view, a homogeneous ideal instrument for radiolocation — an “ideal radar” — is constructed, for which the general radar equation distance and operational characteristics equations are formulated.[66]

The general radar equation is derived for point targets. “Mathematically, a target can be represented by a number of scattering points that intercept the transmitted electromagnetic energy and reflect portions of it towards the transmitting antenna”.[67] Point target is also one of the important idealization in the radar science: “Point targets are objects whose dimensions ... are small compared to the illumination ... by the radar at the target site.“ Then radar equation is formulated for extended targets (see **Fig. 14**). From a radar signal and/or a series of signals can be obtained following information: distance or range, velocity and/or speed, direction[68], azimuth and change of the azimuth over time, size of the target etc. There are a different procedures for their management. For example, the range “is measured as the time difference between the echo-signal and a corresponding reference. As a reference the transmission signal is normally marked and the timestamp between is saved at the receiver”.[69] “The radar (range) equation is “a mathematical expression for primary radar that, in its basic form, relates radar parameters such as transmitter power, antenna gain, wavelength, effective echo area of the target, distance to the target, and receiver input power. The basic equation may be modified to take into account other factors, such as receiver noise, signal processing, attenuation caused by a radome, attenuation due to atmospheric losses or precipitation, and various other losses and propagation effects.”[70]

---

[64] D. Barton. Radar System Analysis. Prentice-Hall, 1964, p. 24. “Rayleigh scattering is a theory that describes scattering characteristics that are smaller than the wavelength of radiation that they encounter. Objects of this size do not scatter all wavelengths evenly. Therefore, Rayleigh scattering is concerned with describing the difference between the particle size and the wavelength of the radiation. When radars go to clear air mode (non precipitation detection) they are trying to tune their wavelengths and band widths for detection of dust particles. Clear air mode is often used to identify dry microbursts by tracking the dust particles picked up by the strong winds” (Basic Radar Theory. - http://snrs.unl.edu/amet451/marsh/theory.html).

[65] “Radar system analysis must take into account the effects of the environment in which the radar operates … Atmospheric propagation phenomena affect both target detection and coordinate measurement … ” (D. Barton. Radar System Analysis. Prentice-Hall, 1964, p. viii).

[66] D. Barton. Radar System Analysis. Prentice-Hall, 1964, p. 156

[67] S.A. Hovanessian. Radar system design and analysis. Dedham: ARTECH HOUSE, INC., 1984, p. 46

[68] The first three parameters is the most important and most often evaluated information.

[69] See: W. Wiesbeck. Lecture Script “Radar System Engineering”. 13th Edition WS 2006/2007. Institut für Höchstfrequenztechnik und Elektronik, Universität Karlsruhe, p. 13, 15, 19: www.ihe.uni-karlsruhe.de

[70] David K. Barton, Sergey A. Leonov (Editors). Radar Technology Encyclopedia (Electronic Edition). Boston, London: Artech House, 1998. ISBN 0-89006-893-3

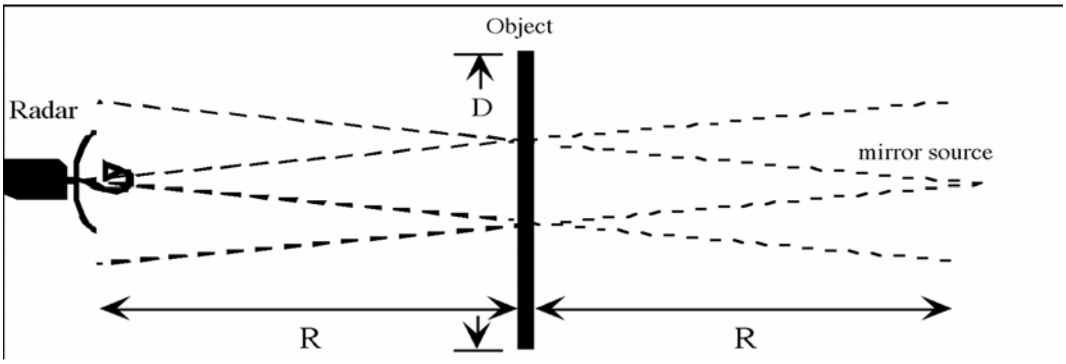


Fig. 14. "Reflection on a flat, extended target. … The mirrored reflection is in relation to a "virtual" source from a distance R behind the target".[71]

An another important idealization is the idealized representation of the signal. In the pulse radar you receive always distorted output pulse. Radar theory proceed from a compromise in the practice. "Great range is incompatible with good range resolution, high accuracy and high scanning speeds. Steep and narrow pulses are necessary but this means increasing the receiver bandwidth and hence the noise factor. If the bandwidth is reduced the pulse is distorted. All these conflicting requirements are considered by the designer. The result is that a radar set designed for use in one role would be of little value in another role. Each application requires different variations in all the variable factors …" The waveforms shown in **Fig 15** are 'ideal', i.e. we have assumed zero rise and decay times. In practice each pulse is more rounded because it takes a finite time to rise and to fall" (see **Fig. 16**). However the ideal waveforms shown are adequate for the purpose of the theoretical representation and calculation.[72]

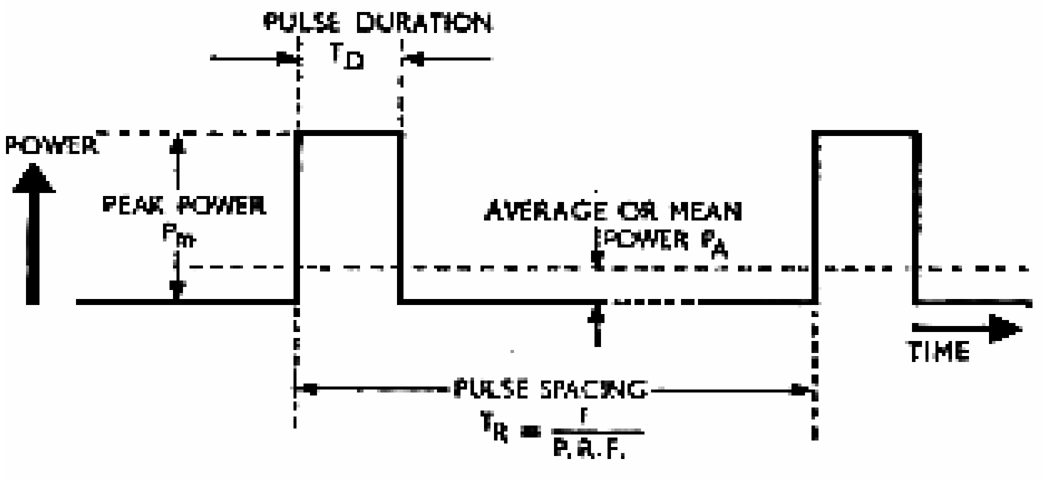


Fig. 15. The ideal waveforms ("ideal pulse").

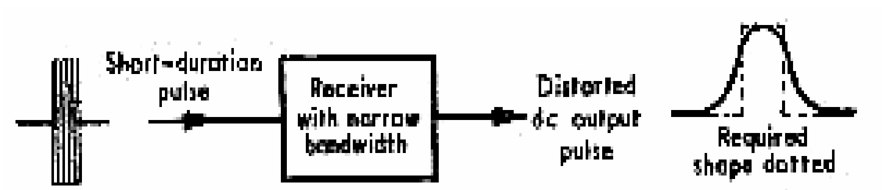


Fig. 16. The real pulse: rounded waveform.

---

[71] W. Wiesbeck. Lecture Script "Radar System Engineering". 13th Edition WS 2006/2007. Institut für Höchstfrequenztechnik und Elektronik, Universität Karlsruhe, p. 13, 15, 19: www.ihe.uni-karlsruhe.de
[72] Radar Theory. - http://www.radarpages.co.uk/theory/ap3302/sec1/ch3/sec1ch340.htm

But already in the radar theory is very important to calculate a radar receiver noise (thermal (ohmic) noise, cosmic and background noise from outer space in the form of plane waves, atmospheric absorption[73] and man-made noise). "For calculating the accuracy of the range measurement one replaces the sine wave with a video pulse" as in **Fig. 17**.[74]

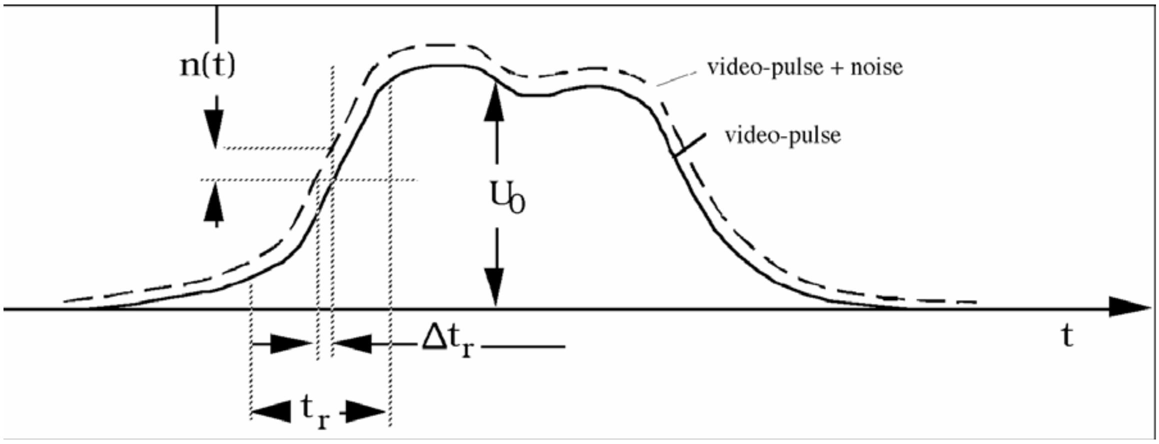


Fig. 17. Video pulse and added noise with edge triggering

Taking into account various losses that take place under real conditions, such basic mathematical representations (calculated for the ideal radar) make it possible to assess quickly the parameters of existing stations, and, due to an operational description of radar, to distinguish in them a fixed set of standard units (multiplier, integrator, threshold device, coordinated filter, time selector, etc.) corresponding to the respective mathematical operations.[75] For example a differentiating circuit is a short CR circuit to convert a square wave input to a series of positive and negative-going pips of voltage (**Fig. 18**). "These pips may be used for timing purposes. They may be obtained by applying a square wave to a short CR circuit and taking the output across the resistor".[76]

---

[73] "In a stationary condition all bodies, which absorb energy, re-radiate the same energy as noise power. This is the radiation theory of black bodies. Would this not be the case then some objects would warm themselves and others would cool themselves down. The transmitting power of the radar will partially be absorbed by the atmosphere and will be re-radiated as noise" (W. Wiesbeck. Lecture Script "Radar System Engineering". 13th Edition WS 2006/2007. Institut für Höchstfrequenztechnik und Elektronik, Universität Karlsruhe, p. 33: www.ihe.uni-karlsruhe.de).

[74] W. Wiesbeck. Lecture Script "Radar System Engineering". 13th Edition WS 2006/2007. Institut für Höchstfrequenztechnik und Elektronik, Universität Karlsruhe, p. 25: www.ihe.uni-karlsruhe.de

[75] All these units are at the same time the operations with signal (in this case with the pulse waveform). "With all radar devices, which are not agile from pulse to pulse, several pulses are reflected from a target with each sample instance. One identifies the summation of all pulses from a target as integration. The detection becomes even better the more reflected energy from the target is received and integrated" (W. Wiesbeck. Lecture Script "Radar System Engineering". 13th Edition WS 2006/2007. Institut für Höchstfrequenztechnik und Elektronik, Universität Karlsruhe, p. 56: www.ihe.uni-karlsruhe.de). "Radar signal processing is an operation in which desired data about a target are extracted from the received radar signal. Signal processing is necessary in performance of all major radar operations: detection, measurement, and, if applicable, recognition and identification. The radar element performing this operation is termed a *signal processor* …" (David K. Barton, Sergey A. Leonov (Editors). Radar Technology Encyclopedia (Electronic Edition). Boston, London: Artech House, 1998. ISBN 0-89006-893-3).

[76] "There are many occasions in radar when we need to convert a square wave input to a series of positive and negative-going pips of voltage" (Radar Theory. - http://www.radarpages.co.uk/theory/ap3302/sec2/ch2/sec2ch272.htm

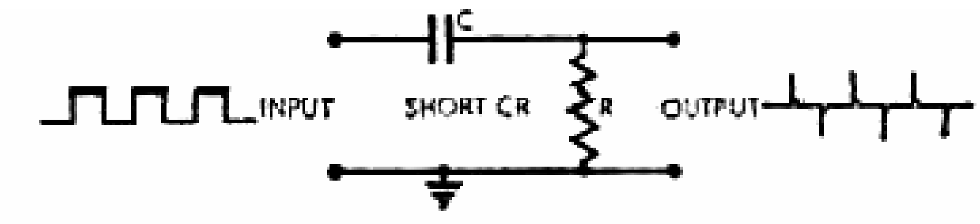


Fig. 18

By certain rules fixed in the theory, these radar units can be used to design for radar varied circuit diagrams to be then realized as various structural plans of existing radar stations.

Radiolocation was developing as a new scientific and engineering discipline closely connected with the needs and demands of engineering practice and industrial production. At this stage, broader use was made of radars not only for military purposes, but also in radio navigation, radio astronomy, geodesy, etc. Individual fields of' research began to differentiate in radiolocation such as active and passive location, analysis of radar signals and development of radar systems' automatic control, etc. Further, developing radio location led to the emergence of related science and engineering disciplines, for example, the theory of antennas and the rapid and broad dissemination of television.

Thus, the first period in the development of radiolocation was characterized by a gradual evolutionary process of transformation, modification and consolidation of a new research trend, then a field of study in radio engineering, then a special science and engineering discipline. As a result, a specific conceptual and mathematical apparatus and generalized theoretical representations of radar theory develop within the framework of the electrodynamic picture of the world. We shall call radiolocation at this stage of evolution "classical" to distinguish it from radar systems engineering which is a modern scientific and research complex and can be called "neoclassical" radiolocation.