RADIO CIRCUITS AND SIGNALS

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РАДИОТЕХНИЧЕСКИЕ ЦЕПИ И СИГНАЛЫ

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The Greek Alphabet

Α α	Alpha	Ι ι	Iota	Ρ ρ	Rho
Β β	Beta	Κ ϰ	Kappa	Σ σ	Sigma
Γ γ	Gamma	Λ λ	Lambda	Τ τ	Tau
Δ δ	Delta	Μ μ	Mu	Υ υ	Upsilon
Ε ε	Epsilon	ν	Nu	Φ φ	Phi
Ζ ζ	Zeta	Ξ ξ	Xi	Χ χ	Chi
Η η	Eta	Ο ο	Omicron	Ψ ψ	Psi
Θ θ	Theta	Π π	Pi	Ω ω	Omega

На английском языке

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PREFACE

Since 1971, when this textbook was last published, radioelectronics has made great progress, necessitating our extensive revision and supplementing of the material, although the same guiding principles have been followed as in the first two editions.

The wide use of discrete and digital radioelectronic circuits has made it impossible to restrict the course on radio circuits and signals to *analog* circuits and signals alone, while the development of integrated microcircuits, based on an extensive application of circuit *synthesis* methods, has prompted us to expand it beyond the study of the techniques of circuit *analysis*, and, finally, the ever increasing introduction of statistical methods in all branches of radio engineering and electronics has required a more comprehensive study of random signals and their transformation in radio circuits.

This edition, therefore, contains five entirely new chapters — Main Characteristics of Random Signals (Ch. 4), Transmission of Random Oscillations Through Linear Circuits with Constant Parameters (Ch. 7), Discrete Processing of Signals and Digital Filters (Ch. 13), Representation of Oscillations by Some Special Functions (Ch. 14), and Elements of Synthesis of Linear Radio Circuits (Ch. 15).

Chapter 5 of the previous edition, dealing with the theory of active linear circuits with feedback loops, has been totally rewritten, and methodological changes have been made in the rest of the material on the basis of criticisms and numerous suggestions made by college teachers and radio specialists.

Seeking to inspire students to do independent research work, we have expanded the scope of the book to include, along with the subject matter for compulsory study, some additional, more complex material for advanced students. This material is printed in small type.

The book is so arranged that minor abridgements, which may be necessitated by the inadequate theoretical knowledge of the students, will not impair integrity of the presentation.

In conclusion we should like to thank Professor N. N. Fedorov, Senior Readers S. I. Baskakov, and I. V. Belousova, Assistant Lecturer V. I. Bogatkin, Senior Reader V. P. Zhukov, Senior Teacher N. N. Ivanova, Senior Readers V. G. Kartashev, A. M. Nikolaev, and B. P. Pollak, and Senior Teacher V. V. Shtykov of the Radio Engineering Department of the Moscow Power Institute for their careful reading and checking of the original manuscript. We are grateful to Senior Reader L. A. Chinenkov of the Communications Equipment Sub-Faculty of the Novosibirsk Institute of Communications for his numerous valuable comments on the previous edition of this book. Deep appreciation goes to the teaching and research staff of the Radio Engineering Sub-faculty of the Moscow Aviation Institute for their invaluable help in the preparation of the manuscript.

I. S. Gonorovsky

Chapter 1

INTRODUCTION

1.1. BASIC APPLICATIONS OF RADIO ENGINEERING

Modern radio engineering is a powerful tool in speeding up the scientific and technical progress. Radio engineering has penetrated all branches of the national economy, science, industry, our culture and everyday life.

One of the most important applications of radio engineering involves long-distance communication by means of electromagnetic waves. The development of various specialized branches of radio engineering is closely allied to the general use of radio for broadcasting and communication, while television covers steadily expanding regions in many parts of the globe. Radio equipment provides for reliable round-the-clock communication with marine vessels, aircraft, and spaceships. Radio engineering systems enable us to effect interplanetary communications and to provide remote control of apparatus used for exploration of other planets. Such branches of radio engineering as radio detection and ranging (or radar), radio navigation, radio telemetry, and radio control, which just a few years ago were regarded as new techniques, are now in general use.

However, the above applications by no way exhaust all the possibilities of modern radio engineering. Radio methods have penetrated into well-known sciences and led to their qualitative change and further development. New sciences have been born, such as radio physics and radio astronomy.

Radio techniques and methods are widely used in experimental physics, including nuclear physics, in instruments and apparatus measuring transient processes and various non-electrical quantities (pressure, mechanical vibration, small displacements and so on), in studying physical phenomena occurring in the ionosphere, and in time service.

The extensive use of radio methods for solving various problems not associated with radiation of electromagnetic waves has given rise to a novel science that embraces both radio engineering and electronics. This branch of science is commonly referred to as *radioelectronics.*

The ever wider use of high-speed electronic computers for calculations, control and data acquisition is a great achievement of radioelectronics. Cybernetic systems playing a decisive role in process control and automation is one of the major areas of development of radioelectronics. Radioelectronic equipment is widely used in medical studies (for diagnostics) and in the manufacture of artificial organs or devices that are employed to compensate for partially or completely lost functions of a human organism.

From what it is said above we may draw a conclusion that applications of radioelectronics are many-sided and that its role in the future progress of mankind will incessantly gain in importance.

Since the very date of invention of the first radio receiver by A. S. Popov in 1895 and up to the present day the main application of radio engineering has been *transmission of information* by means of electromagnetic waves. This is a principal difference between radio engineering and electrical engineering, since the latter deals with transmission of energy (e.g., long-distance transmission of electric power over a high-voltage line) instead of information.

1.2. TRANSMISSION OF SIGNALS. RADIO FREQUENCY BANDS AND PROPAGATION OF RADIO WAVES

Thus, the transmission of a message over a distance is the basic task of radio engineering. Distance separates the transmitter and the receiver, the sender of control signals and the actuating mechanism, the process being studied and the measuring system, the source of cosmic radiation and the recorder of a radio telescope, and individual units of a computer. In other words, distance separates the source of information from its recipient.

The distances over which signals are transmitted may be either insignificant (transmission of commands from one unit of an electronic computer to another) or extremely large (intercontinental or cosmic communications). Messages can be transmitted over wire (cable) or waveguide lines or through free space. It is obvious that to transmit a signal, such physical processes should be used as possess the ability to propagate through space. These include electromagnetic oscillations (radio waves) that radio engineering makes use of. Any physical process employed as a carrier of information must be capable of taking the whole set of states that could be used to establish unambiguously the corresponding state of the object or process that provides the information to be transmitted, i.e., the source of information.

To this end, radio waves are subjected to *modulation*. The process of modulation consists in that a high-frequency oscillation capable of propagating over vast distances is given some properties characterizing the message to be transmitted. The oscillation is therefore used as a carrier of the message. For this purpose one or several parameters of the oscillation are varied according to the same law as governs the changes of the transmitted message. Depending on the oscillation parameter varied (amplitude, frequency or phase), the following three fundamental types of modulation are distinguished: amplitude, frequency and phase modulation*.

The inverse transformation of electromagnetic waves into the initial signals at the receiving station is called *demodulation* or *detection* (amplitude, frequency or phase, respectively).

As a rule, modulation does not affect the ability of radio-frequency oscillations to propagate in free space; however, a proper choice of the wavelength (or the carrier frequency) is of vital importance for establishing reliable radio communication.

The choice of a frequency band for any particular radio communication system is governed by the following factors.

1. The character of propagation of electromagnetic waves in the given frequency band, depending on the season, time of day, atmospheric conditions, solar radiation, etc.

2. Technical capabilities: directional radiation, use of an appropriate antenna system, generation of high-power oscillations and their control (modulation), receiver design, etc.

3. Interference and noise characteristics in the given band.

4. The character of the message to be conveyed, that is the "spectrum width" of the modulating frequencies and the desired method of modulation (frequency, amplitude, etc.).

In practice those sub-bands are utilized that provide for the best conditions of propagation of radio waves and sufficiently satisfy all the other requirements stated above.

At present, radio engineers and scientists are investigating insufficiently known wavelengths with a view to mastering extremely low and high frequencies, including light waves. This is not so strange as it might appear at first sight, because radio and light waves are of the same nature: they are both electromagnetic waves.

The practical subdivision of electromagnetic waves into bands is given in Table 1.1.

Communication with the use of myriametric and kilometric waves, which was used in radiotelegraphy in the early days of radio engineering, suffers from the following serious disadvantages.

First, it is necessary to have a transmitter of a very high power output to compensate for the heavy absorption of the surface wave energy during its travel along the earth surface.

Second, these waves cannot be used for transmission of complex signals, because of the extremely high ratio of the signal spectrum width to the carrier frequency.

Hectometric waves are widely used in radio broadcasting. Radio waves longer than 1,000 m provide for stable reception, but they are difficult to utilize for long-distance communication, because

* There are also various types of pulse modulation, based on changing the parameters of a train of electric pulses.

Table 1.1

Waves	Wavelength range	Frequency range	Obsolete terms
Decamegametric	100,000 to 10,000 km	3 to 30 Hz	
Megametric	10,000 to 1,000 km	30 to 300 Hz	
Hectokilometric	1,000 to 100 km	300 to 3,000 Hz	
Myriametric	100 to 10 km	3 to 30 kHz	Super-long waves
Kilometric	10 to 1 km	30 to 300 kHz	Long waves
Hectometric	1,000 to 100 m	300 to 3,000 kHz	Medium waves
Decametric	100 to 10 m	3 to 30 MHz	Short waves
Metric	10 to 1 m	30 to 300 MHz	
Decimetric	100 to 10 cm	300 to 3,000 MHz	
Centimetric	10 to 1 cm	3 to 30 GHz	
Millimetric	10 to 1 mm	30 to 300 GHz	
Decimillimetric	1 to 0.1 mm	300 to 3,000 GHz	Submillimetric waves
Light	Less than 0.1 mm	Higher than 3 GHz	

Note. Wavelength λ is related to oscillation period T or frequency $f = 1/T$ by the relation $\lambda = cT = c/f$, where $c = 3 \times 10^8$ m/s is the velocity of propagation of electromagnetic waves in a vacuum.

of the considerable absorption of the surface wave energy. Therefore, these waves are mainly employed for local broadcasting within zones several hundred kilometres in radius. Only a few stations are known which have super-high power output and cover large areas. The USSR with its vast territory has the most powerful radio stations operating in this frequency range.

The decametric waves are advantageous in that long distances can be covered with a transmitter of comparatively low power output, and directional radiation is possible. The main disadvantage is the variation of the level of the received signal (fading), often accompanied by heavy distortion of complex signals consisting of a large number of components having different frequencies. Interference conditions, which depend on frequency, can be different for different components of the signal spectrum. This phenomenon, known as selective fading, results in a temporary dropout of individual components from the spectrum of the signal or, on the contrary, in the amplification of the amplitudes of these components. Thus, at the receiving end, the correct relation between individual spectrum components of the signal becomes disturbed and its tone and intelligibility distorted. The wider the signal spectrum, the stronger the effect of selective fading, therefore such complex signals as those used in television practically cannot be transmitted on decametric waves.