Lesson 6. MOS TECHNOLOGY

I. INDEPENDENT WORK

In the Laboratory

1. Skimming Reading

I. a) Listen and repeat after the speaker. b) Memorize the following abbreviations.

MOS — metal-oxide-semiconductor transistor;
SSI — small-scale integration;
MSI — medium-scale integration;
LSI — large-scale integration;
ULSI — ultra large-scale integration;
MOSLSI — large-scale integration of metal-oxide-semiconductor transistor;
NMOS — n-channel metal-oxide-semiconductor transistor;
CMOS — complementary metal-oxide-semiconductor transistor.

II. a) Listen, repeat and memorize the following words and word combinations. b) Check if you know their meanings.

Threefold тройной; feasible возможный, существенный; somewhat несколько; dynamic circuit techniques методы построения динамических схем; a steadily increasing fraction постоянно растущая доля (часть).

III. a) Listen and repeat after the speaker. b) Analyse the structure of the following terms. Translate them.

A single integrated circuit chip; small-scale integration; large-scale integration; equivalent gates; first commercial digital circuits; a new identifier; ultra large scale integration; two distinct classifications; standard parts; many system manufacturers; custom circuits; suitable standard parts; a specific application; small-scale digital integrated circuits; large-scale integrated digital memory and microprocessor circuits; the most important advantage; bipolar circuits; fabricated process; fewer critical defects; bipolar circuit fabrication; dynamic circuit technique; a given circuit function; internal dimensions; a great many variations of MOS technology; zero power consumption; a reverse-biased p-n junction; a typical integrated-circuit p-n junction capacitor.

Text A

SCALE OF INTEGRATION

I. a) Listen to the text, mind the English intonation. b) Read the text to yourself and grasp the main idea of it.

In practice, many simple digital schemes or gates are manufactured on a single integrated circuit chip. Although there are no universally accepted definitions for levels of complexity, when between 1 and 10 gates are included on a chip, the usual term referring to this level of complexity is small-scale integration (SSI).

Medium-scale integrated circuits (MSI) are generally considered to include 10 to 100 gates on a chip, while large-scale integration (LSI) refers to complexities in the range of 100 to approximately 10,000 gates or bits of memory per chip. The term very large scale integration (VLSI) is commonly used for integrated circuit chips containing more than 10,000 equivalent gates; the first commercial digital circuits at this level of complexity became available about 1980. Ultimately it may be possible to incorporate a million or more gates on a chip; a new identifier such as ultra large scale integration (ULSI) may come into common usage.

Two distinct classifications for integrated circuits are as **standard parts** (components used by many system manufacturers) or **custom circuits** (components designed and manufactured for one customer). Custom circuits are used when suitable standard parts are not available, or to reduce costs by providing exactly the function needed for a specific application.

2. Average Reading

Text B

METAL-OXIDE-SEMICONDUCTOR (MOS) TRANSISTOR

I. a) Listen to the text. b) Read it (time limit is 3 min.). c) Find the part of it dealing with the most important advantage of MOS circuits over bipolar circuits for LSI. Translate it.

Small-scale digital integrated circuits based on complementary MOS technology have been in use for many years. MOS technology is the basis for most of the large-scale integrated (LSI) digital memory and microprocessor circuits. The most important advantage of MOS circuit over bipolar circuits for LSI is that more transistors and more circuit functions may be successfully fabricated on a single chip with MOS technology. The reason for this are threefold. First, an individual MOS transistor occupies less chip area. Second, the MOS fabrication process involves fewer steps and as a result achieves fewer critical defects per unit chip area than in bipolar circuit fabrication. This makes feasible somewhat larger chips in MOS technology. Third, dynamic circuit techniques that require fewer transistors to realize a given circuit function are practical in MOS technology but not in bipolar technology. The result of these differences is that MOSLSI circuits are significantly cheaper to manufacture than bipolar circuits of equivalent function. Consequently, MOSLSI circuits are making up a steadily increasing fraction of the total market for digital LSI.

ASSIGNMENTS

I. a) Choose the key sentences from the Text A and compare them with the title of the text. b) Say what the text is about.

II. Skim through the Text B and find the part of it dealing with the most important results of using MOS technology.

III. Find the part of the Text B containing information about differences in MOSLSI circuits and bipolar circuits. Discuss it.

IV. Answer the following questions.

1. What are manufactured on a single integrated circuit chip? 2. Are there any universally accepted definitions for levels of complexity? 3. What are MSI generally considered? 4. What term is commonly used for integrated circuit chips containing more than 10,000 equivalent gates? 5. When did the first commercial digital circuits at this level of complexity become available? 6. What are two distinct classifications for integrated circuits? 7. When are custom circuits used?

V. Prepare a dialogue on your own situation.

VI. Make up a plan of the Text B.

VII. Retell the text according to your plan.

II. CLASSWORK

PRE-TEXT EXERCISES

I. Be sure that you know these words.

Significant feature отличительная особенность; very sharp *зд.* очень серьезный; in contrast в противоположность; steady устойчивый; capability способность; shrink сокращать; furthermore более того; coin измышлять, создавать (новые слова); prevalent широко распространенный; wristwatch часы-браслет.

II. Find the following word-combinations in the Text C and translate the sentences containing them.

Pattern definition capability возможность четкого воспроизведения структуры; self-aligned silicon gate NMOS кремниевые приборы n-МОП с самосовмещенным затвором; complementary MOS (CMOS)

technology технология К-МОП; zero power consumption нулевая потребляемая мощность; for both logic states для обоих логических состояний.

III. a) Find attributes in the following word-combinations and define the parts of speech they are expressed by. b). Translate them into Russian.

The internal dimensions of individual devices; sharp improvements; circuit speed; the most prevalent version of MOS technology; the great advantage of CMOS digital circuits; essentially zero power consumption; a typical integrated-circuit p-n junction capacitor.

Text C

ALTERNATIVE MOS PROCESSES

I. a) Read the text. b) Speak on a great many variations of MOS technology.

A significant feature of MOS circuits is that reductions in the internal dimensions of individual devices result in very sharp improvements in circuit speed. In contrast, bipolar circuit speed improves only gradually as internal dimensions are similarly reduced. With the steady improvements in pattern definition capability, the difference in performance between bipolar and MOS circuits has steadily become smaller. For LSI circuits, the speed difference has shrunk from a factor of 10 or more in 1970 to a factor of 2 or less in 1980.

A great many variations of MOS technology have been and continue to be used. Furthermore, the commercial reasons, manufacturers of components often coin their own name or acronym for what may be a process technology used by others under a different name.

The most prevalent versions of MOS technology today is self-aligned silicon-gate NMOS. Modern versions of this process employ a technique known as local oxidation to increase circuit density and performance.

Complementary MOS (CMOS) technologies provide both n-channel and p-channel devices in one chip, at the expense of some increase in fabrication complexity and chip area compared to basic NMOS. The great advantage of CMOS digital circuits is that they may be designed for essentially zero power consumption in steady-state condition for both logic states. Power is consumed only when circuits switch between logic states; average power consumption is usually much smaller than for NMOS circuits. CMOS is widely used for digital wristwatches and other battery-powered equipment, and it is coming into wider use in computers and communication equipment.

ASSIGNMENTS

I. Answer the following questions embracing the contents of the Text C.

1. What is a significant feature of MOS circuits? 2. How does bipolar circuit speed improve as internal dimensions are similar

reduced? 3. When has the difference in performance between bipolar and MOS circuits become steadily smaller? 4. From what factors has the speed difference shrunk in 1970 and 1980? 5. What is the most prevalent version of MOS technology? 6. What technique do modern versions of this process employ? 7. What does complementary MOS (CMOS) technologies provide?

II. a) Read the text again and ask additional questions embracing its contents. b) Combine your answers into a short summary of the text.

III. Find the part of the text containing information about the great advantage of CMOS digital circuits. Translate it.

IV. Pick out all technical terms from the Text C and translate them.

V. Make up a plan of the text.

VI. Speak on the topic according to your plan.

VII. Review the text in written form.

VIII. Translate the text to be sure you understand it well.

4. Searching Reading

PRE-TEXT EXERCISES

I. Match the following English words and word-combinations with the Russian ones.

island	подбор
inevitable	точно
further defects	простота изготовления
relative permittivity	поверхностные взаимосоединения
it may be regarded	ранее рассмотренный
precisely	выход годных схем
simplicity of fabrication	конденсатор с параллельными пластинами
adjustment	неизбежный
circuit yield	сильно диффундированный
previously considered	островок
heavily diffused	она может быть рассмотрена
parallel-plate capacitor	*зд.* другие недостатки
surface interconnection	*зд.* неблагоприятно
offset	относительная проницаемость
adversely	свести на нет

II. Pick out all technical terms from the Text D and translate the sentences with them.

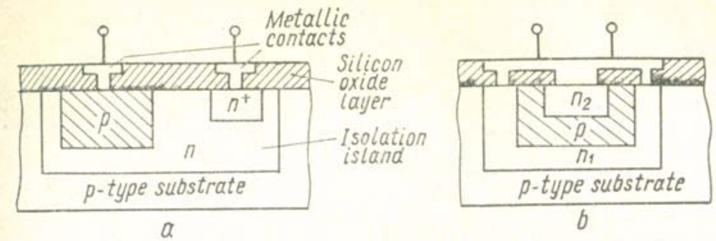

Fig. 4.14. Junction capacitors for integrated circuits:
a a typical junction capacitor; *b* a junction capacitor with increased capacitance.

III. Memorize the reading of the following formulas.

1. $C = \frac{\varepsilon_r \cdot \varepsilon_0 \cdot A}{d}$ farads — *C* is equal to ε sub *r* multiplied by ε sub 0 multiplied by *A* divided by *d* farads.

2. pF/mm² — p multiplied by F divided (per) mm squared.

Text D

CAPACITOR FOR INTEGRATED CIRCUITS

I. Read the text and say what it is about.

Capacitor for integrated circuits fall into two categories: a) The p-n junction type. b) The thin film or MOS type.

A p-n junction capacitor uses the capacitance of a reverse-biased p-n junction. A typical integrated-circuit p-n junction capacitor is shown in Fig. 4.14*a*. It is formed in the silicon chip simultaneously with transistor fabrication. Thus the emitter base junction or the collector-base junction can be utilized, e. g. for a collector-base p-n capacitor, the p-type region may be diffused into the isolation n-type island at the same time as transistor base formation. The n^+-type contact region is formed into the island simultaneously with diffusion for transistor emitter regions.

The resulting capacitance associated with the p-n junction depends upon: a) The junction area. b) The resistivity of the two region utilized. c) The magnitude of the reverse-biased voltage. A higher value type of junction capacitor is shown in Fig. 4.14*b*. Two n-type region n_1 and n_2, sandwich a p-type region, resulting in an increase in junction area.

From Fig. 4.14 it may be noted that an unwanted capacitor is formed by the reverse-biased n-type isolation island and the p-type substrate. Further defects of junction capacitors are their voltage dependence and the inevitable leakage current associated with reverse biased p-n junctions.

The principle of the thin-film integrated circuit capacitor is that of the parallel-plate capacitor, i. e. a capacitor is formed when two

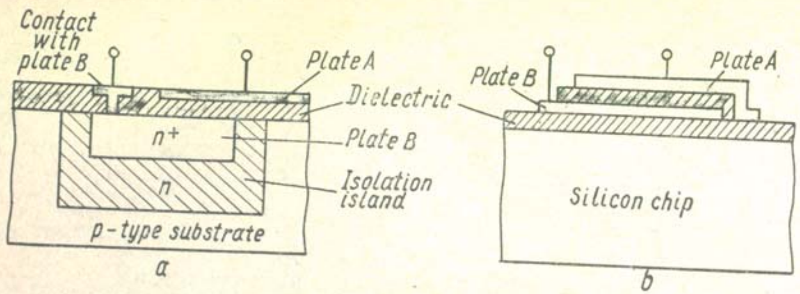

Fig. 4.15. Thin-film capacitors for integrated circuits:
a metal oxide capacitor; *b* thin-film capacitor.

conducting plates are separated by a dielectric material. The total capacitance produced, providing the area of the plates is large in relation to the distance between them, is given by

$$C = \frac{\varepsilon_r \cdot \varepsilon_0 \cdot A}{d} \text{ farads},$$

where ε_r is the relative permittivity of dielectric,
ε_0 is the permittivity of free space (8.85×10^{-12} farads/metres),
A is the area of plates in square metres,
d is the distance between plates in metres.

There are many different forms of thin film capacitors. Fig. 4.15 shows one type which is very widely used — it is referred to as metal oxide silicon capacitor or MOS capacitor.

Plate *B* consists of a heavily diffused n^+ region that is diffused into the isolation island at the same time as transistor-emitter diffusion. The resistivity of this region is so low that it may be regarded as a conducting plate.

The dielectric layer is usually a film of silicon oxide of precisely controlled thickness. The high dielectric strength of silicon oxide makes it possible to have a very thin film, in the order of 0.05 μm which gives a capacitance of 600 pF/mm² with a safe breakdown voltage.

Plate *A* consists of a thin layer of aluminium that is deposited at the same time as metallization of the surface interconnections.

The advantages of this construction are its non-polarization and its simplicity of fabrication. The only additional processing step is adjustment of the thickness of the dielectric layer. Fig.4.15*b* shows a second type of thin-film capacitor that is fabricated entirely on top of the chip. It has an advantage over the previously considered thin-film capacitor in that it may form over previously diffused elements. Further advantages are that a wider choice of dielectric materials may be used and adjustment of the final capacitance may be obtained by abrasion of the top plate. These advantages are somewhat offset since the construction requires additional processing steps which adversely affect the cost and circuit yields.

I. Answer the following questions embracing the contents of the Text C.

1. What are the categories of capacitors for integrated circuits? 2. What capacitance does a p-n junction capacitor use? 3. Where is a typical integrated circuit p-n junction capacitor shown? 4. Is it formed in the silicon chip simultaneously with transistor fabrication? 5. What does the resulting capacitance associated with the p-n junction depend on? 6. How is an unwanted capacitor formed? 7. What are further defects of junction capacitors? 8. What is the principle of the thin-film integrated circuit capacitor? 9. By what formula is the total capacitance produced? 10. Are there many different forms of thin film capacitors? 11. What is shown in Fig. 4.15*a*? 12. What does plate B consist of? 13. What is the dielectric layer? 14. What does plate A consist of? 15. What are the advantages of this construction?

II. Examine Figs. 4.14 and 4.15. Describe them.

III. Discuss the problem of capacitors for integrated circuits using illustrations.

IV. Speak on:

1. Discrete transistor.
2. Integrated circuit transistor using buried n^+ layer.

V. Prepare a dialogue on the important steps involved in the manufacture of one widely used type of integrated circuit transistor.

VI. Look through the latest magazines and find additional information on the topic of the lesson. Discuss it with your fellow-students.

III. GRAMMAR EXERCISES

I. Find the verbs in Perfect Tenses in the following sentences and translate them.

1. Small-scale digital integrated circuits based on complementary MOS technology have been in use for many years. 2. With the steady improvements in pattern definition capability, the difference in performance between bipolar and MOS circuits has steadily become smaller. 3. For LSI circuits, the speed difference has shrunk from a factor of 10 or more in 1970 to a factor of 2 or less in 1980. 4. A great many variations of MOS technology have been and continue to be used.

II. Put as many questions as you can to different parts of the following sentences.

1. MOS technology is the basis for most of the large-scale integrated (LSI) digital memory and microprocessor circuits. 2. The individual MOS transistor occupies less chip area. 3. The MOS fabrication process involves fewer steps. 4. MOSLSI circuits are significantly cheaper to manufacture than bipolar circuits of equivalent function. 5. MOSLSI circuits are making up a steadily increasing fraction of the total market for digital LSI. 6. Reductions in the internal dimensions of individual devices result in very sharp improvements in circuit speed.

III. a) State the forms and the functions of the Participles in the following word-combinations. b) Translate them into Russian.

Integrated circuit chip; the term reffering to this level; integrated circuit chip containing more than 10 000 equivalent gates; components used by many system manufacturers; components designed and manufactured for one customer; the function needed for a specific application; small-scale digital integrated circuits based on complementary MOS technology; a given circuit function; a steadily increasing fraction; a technique known as local oxidation.

IV. Find modal verbs with the Passive Infinitive in the Text D and translate the sentences with them.

Chapter V. ELECTROAUTOMATION AND TELEMECHANICS

Lesson 1. THE LAPLACE TRANSFORM

I. INDEPENDENT WORK

In the Laboratory

1. Skimming Reading

PRE-TEXT EXERCISES

I. a) Make sure that you know these words. Say what Russian words help you to guess their meanings. b) Repeat these words after the speaker.

Theory, analyse, synthesize, engineering, system, electrical, general, characteristic, function, complex, integral, transformation, limit, theorem, sinusoid, component, characterize, pole, signal, diagram, form.

II. a) Listen, repeat and memorize the following words and word-combinations. b) Check if you know their meanings.

Transient переходный, неустановившийся; die down v. затухать, замирать; domain область; obey v. подчиняться; list список; height [ai] высота; solution решение; critical value критическое значение; reference table справочная таблица; steady-state condition установившееся (стационарное) состояние; complex variable комплексная переменная; steady-state solution установившееся (стационарное) решение; integral converge сходимость интеграла; single-sided односторонний; that is the case так бывает в случае, когда; for the unit step change для изменения в виде единичного скачка; linear integral transform линейное интегральное преобразование; the order of difficulty порядок трудности; evaluation of the integral оценка интеграла; transform pairs пары преобразований (взаимообратные преобразования); conventional calculus обычный расчет; single-valued однозначный; first-order time derivative первая производная во времени.

III. Memorize the reading of symbols and formulas. Repeat them after the speaker.

$f(t)$ — a function of [ti:]; $t < 0$ — [ti:] less than zero; $t > 0$ — [ti:] greater than zero;

$L[f(t)] = F(s) = \int_{0^-}^{\infty} e^{-st} \cdot f(t)\,dt$ — Capital [el], square bracket opened function [ef] of [ti:] square bracket closed, equals capital [ef] of [es] equals the integral from [ou] minus to the infinity of [i:] to the minus [es ti:] power multiplied by function of [ti: di: ti:].

IV. a) Translate the following word-combinations. b) Define the attributes and say what part of speech they are expressed by.

The Laplace transform theory; engineering system; particular electrical network; more understanding; introduction of any waveshape; frequency dependent functions of a complex variable; single-sided Laplace transform; a linear integral transform; ordinary differential equation.

Text A

THE AIM OF THE TRANSFORMATION

I. a) Listen to the text, mind the English intonation. b) Read the text to yourself and grasp the main idea of it.

The Laplace transform theory allows one to analyse and synthesise engineering systems and in particular electrical networks with less effort, greater accuracy and more understanding than engineers can usually develop using conventional calculus.

The Laplace transform is a general method that permits the introduction of any waveshape into a circuit and deals with transient as well as steady-state solution. The aim of the transformation is to allow one to think of the characteristics of systems and networks in the *s*-domain.

2. Average Reading

Text B

THE SINGLE-SIDED LAPLACE TRANSFORM

I. a) Listen to the text. b) Read it (time limit is 3 min.). c) Find the part of it dealing with the Laplace transform. Translate it.

The Laplace transform converts a function in the time domain $f(t)$, defines for $t > 0$, to a function in the *s*-domain, and is defined as

$$L[f(t)] = F(s) = \int_{0^-}^{\infty} e^{-st} f(t)\,dt, \quad (5.1)$$

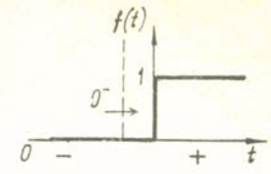

Fig. 5.1. A waveform for unit step change.

where $s = \sigma + j\omega$ is the Laplace complex variable. Normally σ is positive and sufficiently large to make the integral converge. Thus, this transformation relates time function to frequency dependent functions of a complex variable. Equation (5.1) is called the single-sided Laplace transform because the lower limit of the integral is defined as zero, in this case approached from the $t < 0$ side. This latter point is useful when dealing with functions that are discontinuous at $t = 0$. For example, for the unit step change shown in Fig. 5.1 the limit 0^- is zero, being the value of $f(t)$ at $t = 0$ approached from 0^-. To transform a time function $f(t)$ from the time domain to the *s*-domain using the Laplace transform, $f(t)$ must be zero $t < 0$ and single valued and defined for $t > 0$; it may or may not be defined at $t = 0$.

It is evident from Eq. (5.1) that the Laplace transform is a linear integral transform obeying the superposition theorem. The theorem can be stated as follows: if a time function $f_1(t)$ gives a Laplace transform $F_1(s)$ and a time function $f_2(t)$ gives a Laplace transform $F_2(s)$, then a time function $f_1(t) + f_2(t)$ gives $F_1(s) + F_2(s)$. The use of this transform reduces the order of difficulty of a problem because discontinuous in time, for example as shown in Fig. 5.1, are replaced by continuous function in *s*, while ordinary differential equations are replaced by algebraic equations. Thus having transformed the problem in the *s*-domain it is usually easy to write down the Laplace transform of the solution.

ASSIGNMENTS

I. a) Choose the key sentences from the text A and compare them with the title of the text. b) Say what the text is about.

II. Skim through the Text B and find the part of it dealing with the use of the Laplace transform. Translate it.

III. Find the part of the Text B containing information about an example for unit step change.

IV. Answer the following questions embracing the contents of the Text A and the Text B.

1. What does the Laplace transform theory allow? 2. What method is the Laplace transform? 3. What solutions does the Laplace transform deal with? 4. What is the aim of the transformation? 5. What function does the Laplace transform convert?

V. Ask additional questions on the Text A and the Text B.

VI. Make a short summary of the Text B.

VII. Prepare a dialogue on the theorem which a linear integral transform obeys.

VIII. Speak on the Laplace transform theory.

IX. Examine Fig. 5.1 and comment on a waveform for unit step change.

II. CLASSWORK

3. Close Reading

PRE-TEXT EXERCISES

I. Be sure that you know these words and word-combinations.

Step changes ступенчатые изменения; linear second-order system линейная система второго порядка; linear differential equation линейное дифференциальное уравнение; transient term член, связанный с переходным процессом; system transfer function передаточная функция системы; characteristic equation характеристическое уравнение.

II. a) Pay attention to the attributes in these word-combinations and define the parts of speech they are expressed by. b) Translate them.

The output response of a network; a linear second-order system; a linear differential equation; knowledge of the general form of the response; the ratio of a network output; the individual transfer function.

III. Give the initial forms of the following words and translate them.

Transducer, amplifier, various, normally, equation, differential, exactly, transforming, expression, individual.

Text C

TRANSFER FUNCTION

I. a) Read the text. b) Speak on the networks connected in series.

It is often necessary to find the output response of a network or system, for example a transducer and amplifier, for various types of input, for example sinusoids or step changes. Normally the output $c(t)$ and input $r(t)$ of a linear second-order system are related by a linear differential equation of the form

$$Uc(t) + V\frac{dc(t)}{dt} + W\int c(t)\,dt = r(t), \qquad (5.2)$$

and the output $c(t)$ contains two components, a transient term and a steady-state term. It is sometimes necessary to know the output exactly, although often knowledge of the general form of the response is sufficient.

Transforming Eq. (5.2) from the time domain to the s-domain gives the expression

$$C(s) = G(s)\,R(s), \qquad (5.3)$$

It will be seen from Eq. (5.3) that the ratio of a network output $C(s)$ to its input $R(s)$ is the transfer function $G(s)$, if all initial conditions are zero.

If two or more networks are connected in series, provided the process of connection does not affect the networks, the overall transfer function is the product of the individual transfer functions.

ASSIGNMENTS

I. a) Divide the text into logical parts. b) Find the key sentences and translate them.

II. Find the part of the text containing a linear differential equation.

III. Answer the following questions on the Text C.

1. What is necessary to find the output response of a network for? 2. What are the output $c(t)$ and input $r(t)$ of a linear second-order system normally related by? 3. What components does the output $c(t)$ contain? 4. What is sometimes necessary to know and what is sufficient to know? 5. What will be seen from Eq. (5.3)? 6. What is the overall transfer function if two or more networks are connected in series?

IV. Prepare a dialogue on your own situation.

V. Speak on equations necessary to find the output response of a network or system.

VI. Translate the Text C to be sure you understand it well.

4. Searching Reading

PRE-TEXT EXERCISES

I. Match the following English word-combinations with the Russian ones.

A pole-zero diagram	диаграмма нулей-полюсов
superimpose (on Fig.)	уходящий в бесконечность
transient response to be determined	нестабильная система
the following points regarding the poles of the transfer function	экспоненциально затухающие синусоидальные колебания
unstable system	нанести, наложить (на рис.)
going away to infinity	не затухающие колебания
complex conjugates	экспоненциальный спад
exponential decay	комплексно-сопряженные
exponentially decaying sine waves	определяемая переходная характеристика
continuous oscillation	следующие соображения, касающиеся полюсов функции передачи

II. Pick out all formulas from the Text D and write them with help of words.

III. a) Translate the following word-combinations from the Text D. b) Use them while retelling the text.

We have seen that it is fairly easy to describe; we shall now consider; the position of the poles is far more important; in this respect poles with positive real parts denote; complex poles always occur in pairs; a pole $s = -\sigma\ (\sigma > 0)$ means that.

Text D

POLE-ZERO PLOTS

I. Read the text and say about pole-zero plots.

We have seen that it is fairly easy to describe a system in the *s*-domain by its transfer function and to write down the characteristic equation of the system. It seems reasonable that one should be able to characterize a system in the *s*-plane.

We shall now consider the definitions of poles and zeros. Values of *s* which make a system output $C(s)$ infinite are called poles of $C(s)$. These poles are found by solution of the equations

$$\frac{1}{G(s)} = 0, \quad (5.4); \qquad \frac{1}{R(s)} = 0. \quad (5.5)$$

The position of the poles obtained from Eq. (5.4) on the complex *s*-plane gives information regarding the transient response of the system. The poles obtained from Eq. (5.5) are determined by the input signal and the initial conditions.

Values of *s* which makes $C(s)$ zero are called zeros of $C(s)$ and it is clear that they are obtained from the equations

$$G(s) = 0; \quad (5.6); \qquad R(s) = 0. \quad (5.7)$$

A pole-zero diagram of a system transfer function obtained from Eqs. (5.4) and (5.6), allows the form of the transient response to be determined. The position of the poles is far more important in this respect than that of the zeros. Onto this diagram can be superimposed the pole-zero diagram of a particular input, allowing the form of the output response to be determined.

The following points regarding the poles of the transfer function obtained from the characteristic equation are important:

1. Poles with positive real part denote an unstable system, that is a transient response going away to infinity.

2. Complex poles always occur in pairs, called complex conjugates, and the presence of poles $s = -\sigma \pm j\omega\ (\sigma > 0)$ denotes the presence of exponentially decaying sine waves in the transient response.

3. A pole $s = -\sigma\ (\sigma > 0)$ means that the transient response contains an exponential decay.

4. Poles $s = \pm j\omega$ denote continuous oscillation.

I. Answer the following questions embracing the contents of the Text D.

1. Is it very easy to describe a system in the *s*-domain by its transfer function? 2. What are called poles of $C(s)$? 3. What gives information regarding the transient response of the system? 4. By what are the poles obtained from Eq. (5.5) determined? 5. What points regarding the poles of the transfer function obtained from the characteristi- equation are important?

II. Ask additional questions on the Text D.

III. Combine your answers into a short summary of the text.

IV. Discuss the problem of pole-zero plots.

V. Express your opinion of the topic.

VI. a) Look through the latest magazines and find additional material on the topic. b) Use it for short information and discussion.

III. GRAMMAR EXERCISES

I. Find the Infinitive in the following sentences and translate them.

1. The single-sided Laplace transform allows initial conditions to be introduced into the analysis in a simple direct manner. 2. Normally σ is positive and sufficiently large to make the integral converge. 3. It is easy to write down the characteristic equation of the system. 4. Onto this diagram can be superimposed the pole-zero diagram of a particular input, allowing the form of the output response to be determined.

II. Define the form and function of the Participles in these sentences and translate them.

1. Thus having transformed the problem to the *s*-domain it is usually easy to write down the Laplace transform of the solution. 2. Greater accuracy and more understanding than engineers can usually develop using conventional calculus. 3. This latter point is useful when dealing with functions that are discontinuous at $t = 0$. 4. For example, for the unit step change shown in Fig. 5.1 the limit 0^- is zero, being the value of $f(t)$ at $t = 0$ approached from 0^-. 5. The position of the poles obtained from Eq. (5.4) on the complex s-plane gives information regarding the transient response of the system.

III. Define the tense-forms of the verbs in the following sentences and translate them.

1. The sinusoidal waveforms are being considered. 2. Equation (5.1) is called the single-sided Laplace transform because the lower limit of the integral is defined as zero. 3. It will be seen from Eq. (5.3) that the ratio of a network output $C(s)$ to its input $R(s)$ is the transfer function $G(s)$, if all initial conditions are zero. 4. We have seen that it is easy to desribe a system in the *s*-domain by its transfer function. 5. It seems reasonable that one should be able to characterize a system in the *s*-plane.

Lesson 2. GENERAL PROPERTIES OF FEEDBACK SYSTEMS

I. INDEPENDENT WORK

In the Laboratory

1. Skimming Reading

PRE-TEXT EXERCISES

I. a) Make sure that you know these words. Say what Russian words help you to guess their meanings. b) Repeat these words after the speaker.
Physical, system, component, element, block, analyse, generalize, diagram, summing, produce, situation, general, summarize, information, illustrate, horisontal, stable, original, equilibrium, position, resulting, pole.

II. Check if you know the meaning of these words and word-combinations.
Close-loop gain коэффициент усиления при замкнутой цепи; wide (narrow) bandwidth широкая (узкая) полоса пропускания; low output impedance низкий выходной импеданс; noise effects шумовые эффекты; extraneous disturbances посторонние помехи; property of inversion свойство инвертирования; generalized block diagram обобщенная структурная схема (блок-схема); the gain round the loop усиление во всей цепи; a simple feedback system простая система с обратной связью; summing point суммирующая точка; noise source источник шумов; well-defined gain четко определяемый коэффициент усиления; giving accuracy заданная точность; fast response быстрое реагирование (реакция); remains fairly constant остается почти постоянной.

III. Listen to the reading of formulas from the Text B and write them with help of words.

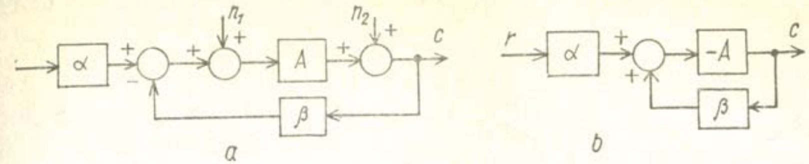

Fig. 5.2. Generalized block diagrams of simple feedback systems:
a input and output in phase; *b* input and output in anti-phase.

Text A

THE BLOCK-DIAGRAMS

I. a) Listen to the text, mind the English intonation. b) Read the text to yourself and grasp the main idea of it.
A physical system may have many components or elements and it is convenient to consider each such element as a block with its own input-output relationship, that is its own transfer function. The blocks representing the various elements of a system are connected to use their functional relationship within the system, thus producing a block diagram for the system. This may well be helpful in analyzing a measuring system, and of course considering each element as a block helps in design of new systems.

2. Average Reading

Text B

CLOSE-LOOP GAIN

I. a) Listen to the text. b) Read it (time limit is 3 min.). c) Find the part of it dealing with the two forms of generalized block diagram of a simple feedback system. Translate it.
The two forms of generalized block diagram of a simple feedback system are shown in Fig. 5.2. Both diagrams illustrate negative feed-back, in that the gain round the loop has negative polarity. In Fig. 5.2*a*, *c* and *r* are in phase, while in Fig. 5.2*b* they are in anti-phase. A fraction α of the quantity to be measured (r) is fed in, and a fraction β of the output quantity (c) is fed back to a summing point which takes the difference and amplifies it by gain A to probuce the output quantity; α, β, and A are transfer functions while n_1, n_2 are noise sources at the input and output of the amplifier respectively. Assuming $n_1 = n_2 = 0$, the following equation expresses the situation of Fig. 5.2 *a*:

$$\alpha r - \beta c = c/A \quad \text{or} \quad \frac{c}{r} = \frac{\alpha}{\beta} \cdot \frac{A\beta}{(1 + A\beta)}. \qquad (5.8)$$

The expression for Fig. 5.2*b* is similar but with a negative sign in front of it. The ratio c/r is called the closed-loop gain, while $A\beta$ is the open-loop gain and both are transfer functions. Provided $A\beta \gg 1$,

$c/r \cong \alpha/\beta$, and c/r is largely independent of A and simply determined by transfer functions α and β. We shall see that main properties of this general system can be summarized as well-defined gain (giving accuracy), wide bandwidth (giving fast response), low output impedance, reduction in noise effects and extraneous disturbances, and the property of inversion. Feedback can be employed to produce high input impedance.

ASSIGNMENTS

I. a) Choose the key sentences from the Text A and compare them with the title of the text. b) Say what the text is about.

II. a) Skim through the Text B and explain the close-loop gain.

III. Answer the following questions embracing the contents of the Text A and the Text B.

1. What are the blocks representing the various elements of a system connected for? 2. Where may this block diagram be helpful? 3. How is the ratio c/r called and what is A in Eq. (5.8)? 4. What do we see in Fig. 5.2 and in Eq. (5.8)?

IV. Ask additional questions on the Text A and the Text B.

V. Combine your answers into a short summary of the texts.

VI. Speak on the two forms of generalized block diagram of a simple feedback system.

II. CLASSWORK

3. Close Reading

PRE-TEXT EXERCISES

I. Be sure that you know these words.

Assessment of stability оценка устойчивости; constant peak-to-peak amplitude постоянная амплитуда; slightly tipped слегка отклоненный; resulting transient response результирующая переходная характеристика; left (right) hand portion левая (правая) половина; negative real part отрицательная реальная часть; the Nyquist criterion критерий Найквиста; root-locus method метод геометрического места корней; the Bode criterion критерий Боде.

II. a) Analyse the structure of the following words. b) Translate them.

Particularly, feedback, measuring, rapidly, stability, peak-to-peak, consideration, slightly, location, *s*-plane, resulting, decreasing, disturbance, right-hand portion, requirement, assessing, root-locus method.

III. Listen to the reading of formula of Eq.(5.9) and write it with help of words.

Text C

ASSESSMENT OF STABILITY

I. a) Read the text. b) Find the part of it describing the concept of stability.

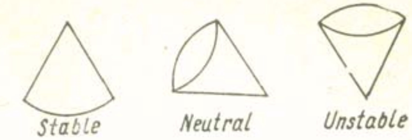

Fig. 5.3. A type of the stability of a cone.

It is important to investigate the output response of a system particularly feed-back measuring system, when the input changes rapidly. This transient response characterizes the stability of the system. A system is defined as stable if its impulse response approaches zero as time approaches infinity. A system is defined as being unstable if with zero input, the output increases indefinitely. If the output of a system has continuous oscillation of constant peak-to-peak amplitude, the system is considered to be neutrally stable. Consideration of the degree of stability of a system often provides valuable information about its behaviour.

The concept of stability can be illustrated by considering a cone placed on a horizontal (Fig. 5.3) surface. When the cone is resting on its base it is said to be stable, because if it is slightly tipped it returns to its original equilibrium position.

On the other hand, if the cone is placed on its tip and released, it falls onto its side, and so this position is said to be unstable.

It was shown that the location in the *s*-plane of the poles of a system indicate the resulting transient response. Poles in the left-hand portion of the s-plane result in a decreasing response for disturbance inputs, while poles in the right-hand portion result in an increasing response. Poles on the j-axis result in a neutral response to a disturbance input. Clearly it is desirable that feedback-measuring system are stable and respond satisfactorily to rapid changes in the quantity to be measured.

A necessary and sufficient condition that a system be stable is that all the poles of the system transfer function have negative real parts. Thus if a system has a transfer function

$$G(s) = \frac{C(s)}{R(s)} = \frac{b_m s^m + b_{m-1} s^{m-1} + \cdots + b_0}{a_n s^n + a_{n-1} s^{n-1} + \cdots + a_0}, \qquad (5.9)$$

the requirement for stability is that all roots of the denominator must have negative real parts. Four basic methods of assessing stability are the Hurwitz-Routh criterion, root-locus method, the Nyquist criterion and the Bode criterion.

ASSIGNMENTS

I. Skim through the Text C and speak on the main idea of it.

II. a) Divide the text into logical parts. b) Choose the key sentences and translate them.

III. Comment on the author's attitude to assessment of stability.

IV. Examine Fig. 5.3 and comment on stability of a cone.

V. Answer the following questions embracing the contents of the Text C.

1. What is necessary to investigate when the input changes rapidly? 2. What does this transient response characterize? 3. How is a system defined if its impulse response approaches zero as time approaches infinity? 4. How is the system defined if, with zero input the output increases indefinitely? 5. When is the system considered to be neutrally stable? 6. What provides valuable information about behaviour of a system? 7. What are four basic methods of assessing stabilit y?

VI. Prepare a dialogue on a necessary and sufficient condition for the system to be stable.

VII. Translate the Text C to be sure you understand it well.

4. Searching Reading

PRE-TEXT EXERCISES

I. Match the following English word-combinations with the Russian ones.

the rest of the system	точный исполнительный механизм
strain gauge	инверсный преобразователь
low power	тензометр, тензодатчик
inverse transducer	остальная часть системы
precision actuator	маломощный

II. Find the following word-combinations in the Text D and translate them.

A block diagram of a simple control system is shown in Fig.; shaft position is measured and compared with; the general functional diagram of a measuring system includes; a most useful application of inverse transducers is.

Text D

FEEDBACK FOR CONTROL AND MEASUREMENT

I. Read the text and say about feedback for control and measurement.

A block diagram of a simple control system is shown in Fig. 5.4*a* Here the actual quantity to be controlled (usually a non-electrical quantity), for example shaft position, is measured and compared with a demanded quantity (usually these quantities are electrical) to produce an error which is amplified to drive an actuator, for example an electric motor, producing power to drive the controlled quantity.

The general functional diagram of a measuring system includes an inverse transducer as an output device. Normally a transducer

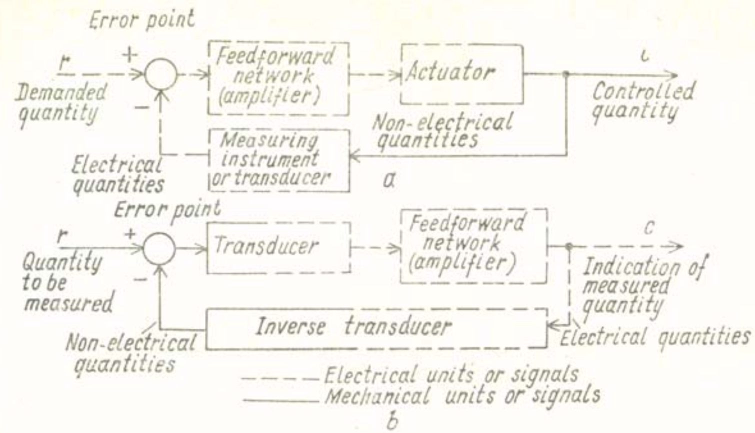

Fig. 5.4. The comparison of two systems:
a the simple control system; *b* the simple feedback measuring system.

and associated circuit has non-electrical input and an electrical output, for example a thermistor, strain gauge, and photodiode, whereas a so called "inverse transducer" has an electrical input and low-power non-electrical output.

A most useful application of inverse transducer is in feedback measuring system. A block diagram of such a system is shown in Fig. 5.4*b* for comparison with the simple control system of Fig. 5.4*a*. In the measuring system the output signal (usually electrical) is converted to a form (usually non-electrical, for example force) suitable for comparison with the quantity to be measured (for example force) . The resultant error is usually transduced into electrical form and amplified to give the output indication.

ASSIGNMENTS

I. Answer the following questions embracing the contents of the Text D.

1. What quantities are measured and compared in a simple control system? 2. What does a measuring system include? 3.What is the difference between a transducer and inverse transducer? 4.What is a most useful application of inverse transducer?

II. Ask additional questions on the Text D.

III. Combine your answers into a short summary of the text.

IV. Speak on a simple control system.

V. Prepare a dialogue on a simple feedback-measuring system.

VI. Examine Fig. 5.4 and comment on:

1. The simple control system.
2. The simple feedback measuring system.

VII. Examine Fig. 5.5 and characterize common filters.

VIII. Look through the latest magazines, find additional information and use it while discussing the topic.

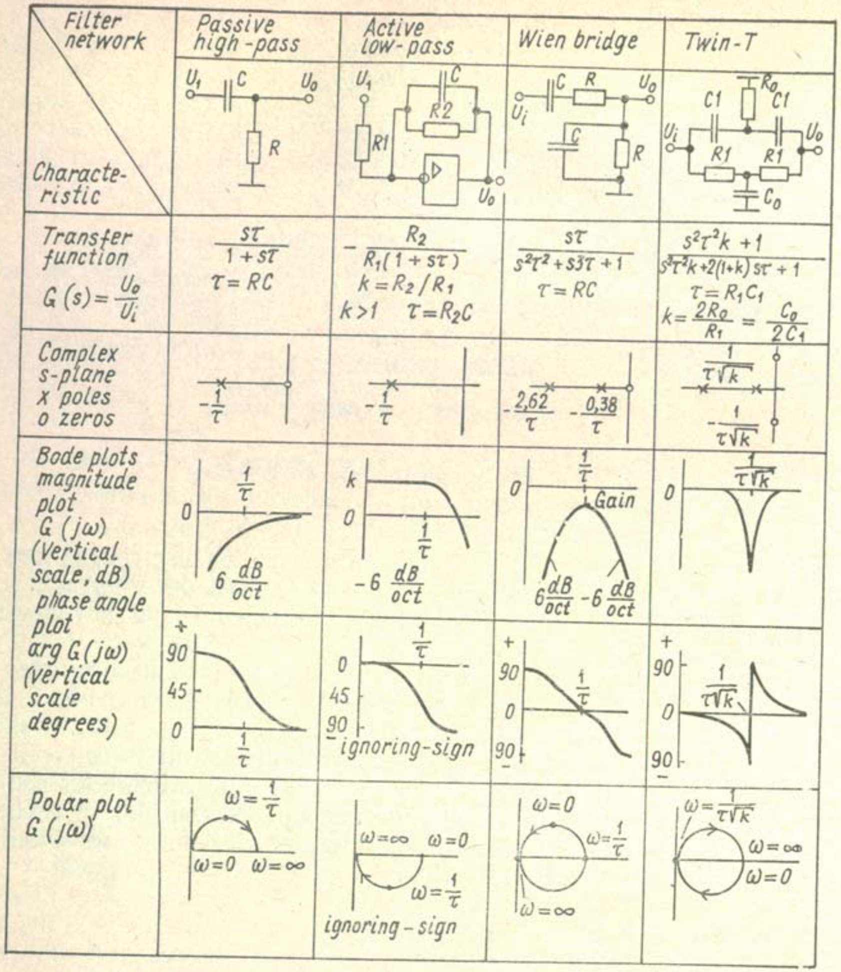

Fig. 5.5. The characteristics of common filters.

III. GRAMMAR EXERCISES

I. a) Analyse the following sentences paying attention to the Gerund and its function in the sentence. b) Translate the sentences.

1. The effect of loading at the output of the feedback system can be best understood by considering the amplifier to be a voltage amplifier with an output impedance *Z*. 2. This may well be helpful in analysing a measuring system. 3. The concept of stability can be illustrated by considering a cone placed on a horisontal surface.

II. Define the functions of the Infinitive in these sentences and translate them.

1. A fraction α of the quantity to be measured (*r*) is fed in, and a fraction β of the output quantity (*c*) is fed back to produce the output quantity. 2. Feedback can be employed to produce high input impedance. 3. When the cone is resting on its base it is said to be stable. 4. If the output of a system has continuous oscillation of constant peak-to-peak amplitude, the system is considered to be neutrally stable.

III. Find Participle I in these sentences. Define its function. Translate the sentences.

1. The blocks representing the various elements of a system are connected to use their functional relationship within the system, thus producing a block diagram for the system. 2. Assuming $n_1 = n_2 = 0$, the following equation expresses the situation of Fig. 5.2*a*. 3. Poles in the left-hand portion of the *s*-plane result in a decreasing response for disturbance inputs, while poles in the right-hand portion result in an increasing response.

Lesson 3. MODULATION AND ENCODING METHODS

I. Independent Work.
In the Laboratory.
1. *Skimming Reading.*
Pre-text Exercises.
Text A. Modulation in Telemetry.
2. *Average Reading.*
Text B. Amplitude Modulation.
Assignments.
II. Classwork.
3. *Close Reading.*
Pre-text Exercises.
Text C. Pulse Modulation System.
Assignments.
4. *Searching Reading.*
Pre-text Exercises.
Text D. Signal Modulation.
Assignments.
III. Grammar Exercises.

I. INDEPENDENT WORK

In the Laboratory

1. Skimming Reading

PRE-TEXT EXERCISES

I. a) Make sure that you know these words. Say what Russian words help you to guess their meanings. b) Repeat these words after the speaker.

Process, (de)modulation, transmission, telemetry, impulse, information, radio, pulse, code, modification, original, sinusoidal, amplitude, parameter, component, proportional, resulting, interval, practical, signal.

II. Listen, repeat and memorize the following words and word-combinations. b) Check if you know the meaning of these words.

Sideband боковая полоса; transmission medium передающая среда (среда передачи); direct transmission прямая передача; land-line telemetry наземная телеметрия; radio frequency (r. f.) радиочастота; wire transmission передача по проводам; original signal первоначальный сигнал; modulated signal модулированный сигнал; amplitude modulation (AM) амплитудная модуляция; relative phase относительная фаза; message signal информационный сигнал; degree of modulation степень модуляции (индекс модуляции); to some extent до некоторой степени; in response to в ответ на; the side sinusoids боковые синусоиды; is just twice the bandwidth of the message signal itself ровно в два раза больше ширины полосы самого сигнала; convey сообщать, передавать.

III. Listen to the reading of formulas from the Text B and write them with help of words.

Text A

MODULATION IN TELEMETRY

I. a) Listen to the text, mind the English intonation. b) Read the text to yourself and grasp the main idea of it.

The process of signal modulation employed depends to some extent on the transmission media to be used. Direct transmission via cable, called land-line telemetry, generally employs either current, voltage, frequency, position or impulses to convey the information. Radio frequency (r. f) telemetry employs either amplitude, frequency, or phase modulation. Such modulation may be used directly as a means of conveying information, or the modulation may be used to convey pulses, sometimes in a coded form.

2. Average Reading

Text B

AMPLITUDE MODULATION

I. a) Listen to the text. b) Read it (time limit is 3 min.). c) Find the part of it dealing with modulation and demodulation.

Modulation is the modification of a carrier waveform, which is usually sinusoidal, in response to the information to be carried. The process of recovering the original signal from the modulated signal is called demodulation. A sinusoidal carrier can be described by the equation: $U = K\sin(2\pi f_c t + \theta)$, (5.10)
where K is the amplitude, f_c the frequency and θ the relative phase of the carrier. In amplitude modulation (AM) K varies, in frequency modulation (FM) f_c varies, and in each case the varying parameter responds to the measurand.

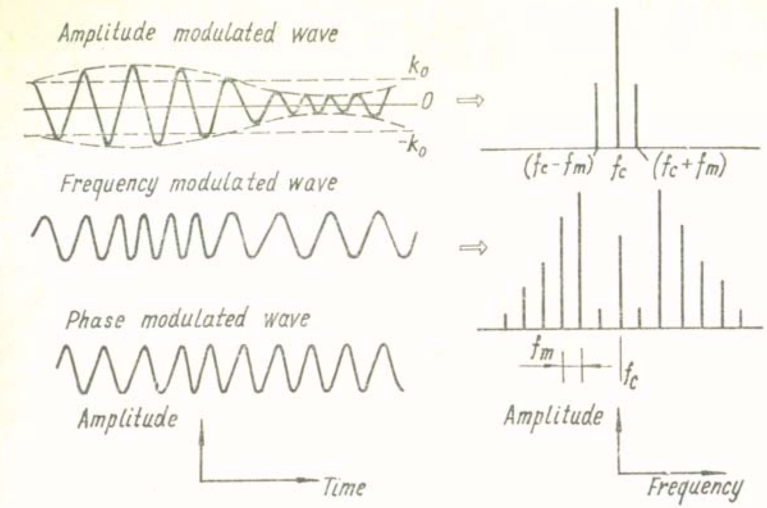

Fig. 5.6. Waveforms and spectral components for different modulation methods.

For AM, the carrier amplitude level swings about its unmodulated value, and for a sinusoidal message signal the expression for K is $K = K_0(1 + m\cos 2\pi f_m t)$, (5.11)
where K_0 is the amplitude of the carrier at frequency f_c when the amplitude of the message signal or modulation at frequency f_m is zero (Fig. 5.6). The actual amplitude of the modulation is $K_0 m$ and m indicated the degree of modulation, for example $m = 1$ means 100 per cent modulation. If Eqs. (5.10) and (5.11) are combined, we obtain assuming $\theta = 0$:

$$U = K_0\left[\sin 2\pi f_c t + \frac{1}{2} m\sin 2\pi(f_c + f_m)t + \frac{1}{2} m\sin 2\pi(f_c - f_m)t\right].$$

Thus the waveform has three frequency components, one at f_c, one at $(f_c + f_m)$ and one at $(f_c - f_m)$, and overall bandwidth of frequencies is $(f_c + f_m) - (f_c - f_m) = 2f_m$. This modulation process has produced new «side» frequency components on each side of the carrier and transformed the frequency of the message from f_m to around f_c (Fig. 5.6). The «side» sinusoids have an amplitude proportional to that of the message signal ($K_0 m$). Any message signal can be represented as a sum of sinusoids modulates the carrier resulting in sidebands about f_c. The bandwidth of an AM signal is just twice the bandwidth of the message signal itself.

ASSIGNMENTS

I. a) Choose the key sentences from the Text A and compare them with the title of the text. b) Say what the text is about.

II. a) Skim through the Text B and find the part of it dealing with the actual amplitude of the modulation. b) Discuss the information about it.

III. a) Find the part of the Text B containing information about message signal represented as a sum of sinusoids. b) Express your opinion of it.

IV. Answer the following questions embracing the contents of the Text A and the Text B.

1. What does the process of signal modulation employed depend on? 2. What does radio frequency (r. f.) telemetry imploy? 3. What is modulation? 4. What is called demodulation? 5. Does the carrier amplitude level swing about its unmodulated value? 6. What is the actual amplitude of the modulation? 7. What modulation process has produced new "side" frequency components on each side of the carrier?

V. Prepare a dialogue on the modulation methods applicable to land-line transmission.

VI. Examine Fig. 5.6 and comment on waveforms and spectral components for different modulation methods.

VII. Speak on the process of signal modulation.

VIII. Translate the following sentences into English.

1. Процесс модуляции сигнала зависит до некоторой степени от используемой среды передачи. 2. Модуляция — это изменение несущей, обычно синусоидальной, в соответствии с передаваемой информацией. 3. Процесс восстановления первоначального сигнала из модулированного сигнала называется демодуляцией. 4. Синусоидальная несущая может быть описана уравнением $U = K \sin (2\pi f_c t + \theta)$. 5. Боковые синусоиды имеют амплитуду, пропорциональную амплитуде информационного сигнала. 6. Ширина полосы АМ сигнала ровно в 2 раза больше ширины полосы самого информационного сигнала.

II. CLASSWORK

3. Close Reading

PRE-TEXT EXERCISES

I. Be sure that you know these word-combinations.

A pulse-amplitude modulation system (PAM) система амплитудно-импульсной модуляции (АИМ); pulse-duration modulation system (PDM) система широтно-импульсной модуляции (ШИМ); pulse-width modulation (PWM) широтно-импульсная модуляция (ШИМ); pulse-position modulation (PPM) фазо-импульсная модуляция (ФИМ); with the exception за исключением; variable pulse width изменяемая длительность (ширина) импульса; practical pulse-coding system практическая система кодирования импульсов; pulse-code modulation (PCM) импульсно-кодовая модуляция (ИКМ); a series of binary digits последовательность двоичных цифр; to be sampled производить выборку, стробировать; each sample value величина каждой выборки; the sampling theorem теорема о дискретном представлении; 7-digit code семиразрядный код; quantum level уровень квантования, the quantizing noise шум квантования.

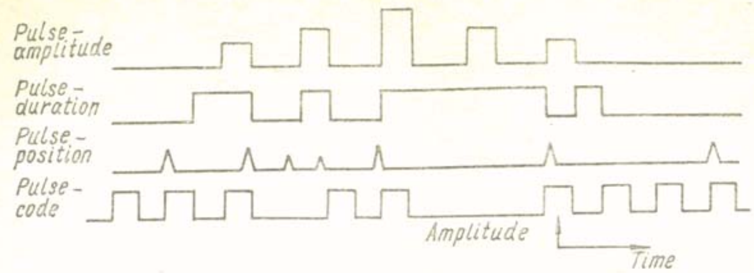

Fig. 5.7. Pulse coding methods and corresponding waveforms.

II. State the function of suffixes in these words and translate them.

Information, modulation, duration, proportion, differentiating, rectifying, transmitter, practical, coding, sending, transmission.

Text C

PULSE MODULATION SYSTEM

I. a) Read the text. b) Find the part of it describing the pulse-duration and pulse-position modulations. Translate it.

The information to be conveyed may be converted to a pulse form for land-line or r. f. telemetry. In pulse-amplitude modulation system (PAM) the carrier is modulated with pulses whose hights carry the information. In pulse-duration modulation (PDM) system, the amplitude of all pulses is constant, but the duration of the pulses varies. In PDM one edge of the pulse is fixed in time sequence and the other edge varies in proportion to the value of the information. This type of coding is also referred to as pulse-width modulation (PWM). Pulse-position modulation (PPM) is similar to PDM with the exception that a short pulse is used in place of the variable pulse width. This can be accomplished by differentiating and rectifying a PDM waveform. The same information can be sent by PPM with much less average power than PDM, since the transmitter is on a much shorter time. The narrow pulse require wider bandwidth for transmission, however.

The most efficient of the practical pulse coding system is that called pulse-code modulation (PCM). It consists of sending analogue information by transforming it into a series of binary digits, as shown in Fig. 5.7. The analogue signal is sampled at regular intervals and then each sample value is converted into a coded form, a process which introduces an error.

The PCM system often employs a 7-digit code, giving 128 quantum levels, and the signal is transmitted using FM, the least significant digit being sent first. Apart from the quantizing noise, no noise is introduced during transmission.