Қазақстан Республикасы білім және ғылым министрлігі

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**«Practical works on radioelectronics» пәні бойынша**

**Дәрістер курсы**

мамандығы: «5B011000-Физика, 5B012800-Физика-Информатика»

Қарағанды 2019

**Theme 1: Semiconductor devices**

*Question:*

*1. Semiconductor Diodes*

*2. Special-Purpose Diodes*

*3. Thyristors*

*4. Transistors*

*5. Bipolar Junction Transistors*

Diodes are useful circuit elements. A *semiconductor diode* is a device having a p-n junction mounted in a container, suitable for conducting and dissipating the heat generated in operation and having connecting leads. Figure 1 shows the schematic symbol of a diode. The p side is called the *anode*. The n side is called the *cathode*. Electronic symbol for a diode looks like an arrow that points from the p side to the n side, from the anode to the cathode. Note that filled triangle of the symbol points in the direction of the forward biased current. A semiconductor diode is a junction between p-type and n-type semiconductors (called p-n junction).

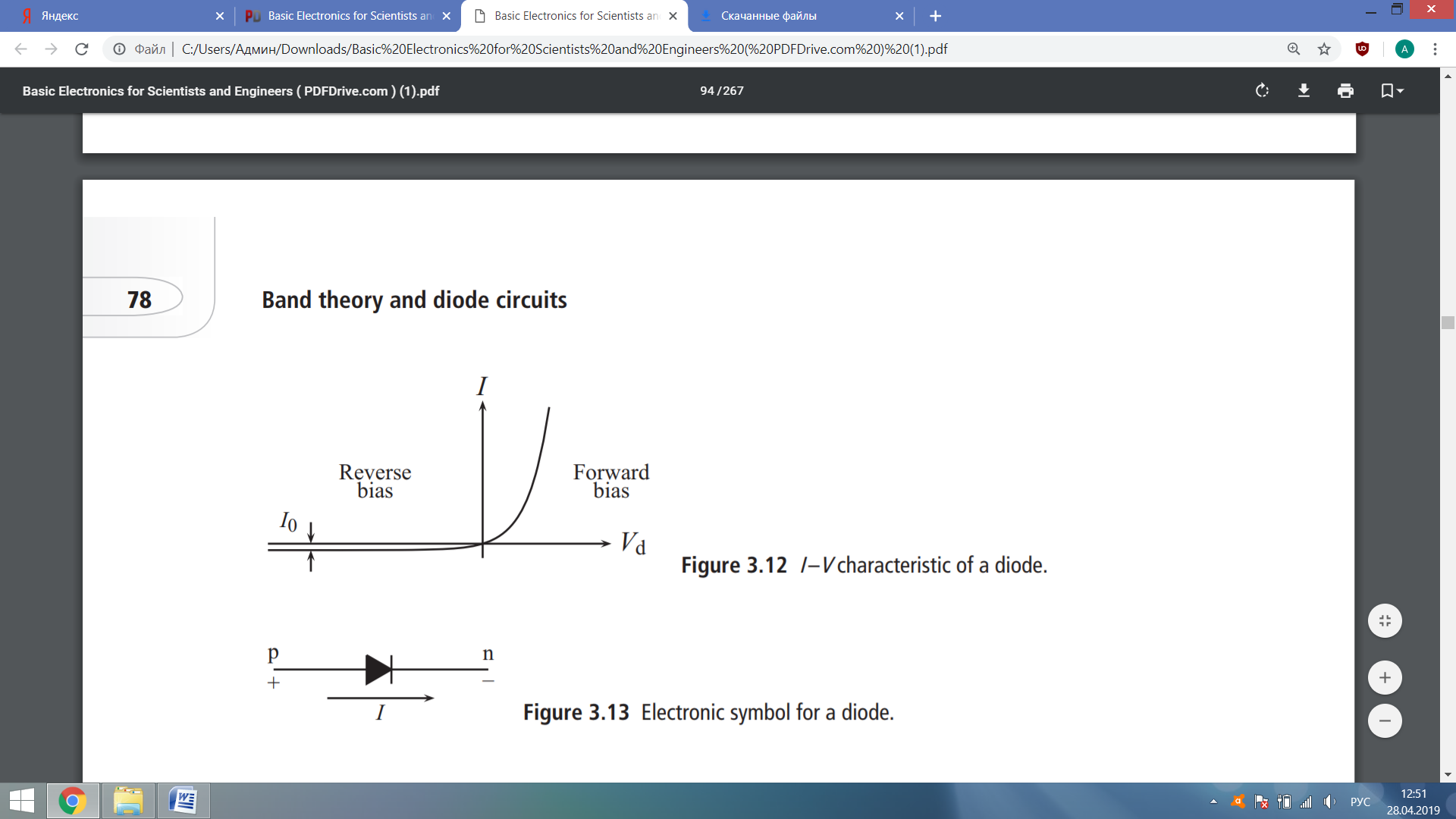


Fig. 1. The diode symbol

Most semiconductor devices contain one or more p-n junctions. The p-n junction is of great importance because it is in effect, the control element for semiconductor devices. A *p-n junction* is a piece of semiconductor material in which part of the material is p-type and part is n-type. In order to examine the charge situation, assume that separate blocks of type and n-type materials are pushed together. Also assume that a hole is a positive charge carrier and that an electron is a negative charge carrier. The behavior of p-n junction (called a diode) can then be summarized as

*I=I0(eeVd/kT – 1),*

where *I0*=*Cexp(-*Δ*E/kT)*; k = 1.38·10-23 J/K is the Boltzmann constant; e = 1.6·10-19 C is the fundamental charge; T is the absolute temperature. A graph of this result is shown in Fig. 2. *I0* is usually very small compared to a typical forward bias current and is thus often approximated as zero.

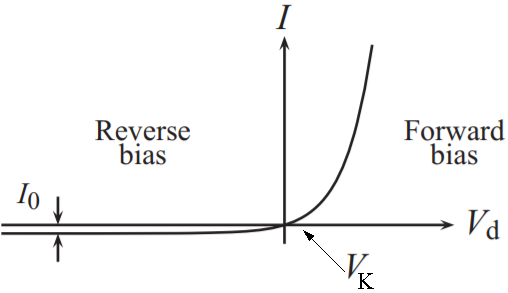


Fig. 2. I-V characteristic of a diode

Diode is a nonlinear device because the graph of its current versus voltage is not a straight line (Fig. 2). All these effects lead to a more complicated relation between voltage and current. Below is a schematic plot of the I-V relation for a diode. This is the forward current I plotted against the forward voltage V; negative values of course indicate that the voltage/current are going in the reverse-biased direction. There are a few features to notice here:

- *Forward conduction*. As the diode is forward-biased, the forward current rapidly increases. But for any forward current, there is a forward voltage drop. A handy number to remember for quick calculations is 0.7 V for the voltage drop, for forward-biased silicon diodes. The drop is somewhat more for high-power diodes, somewhat less for Schottky and germanium diodes.

- *Reverse leakage*. When the diode is reverse-biased, the current is not completely blocked, but some current flows. This is roughly constant over a wide range of reverse-bias voltages, and is usually labelled *IS*, with the “S” for saturation current.

- *Reverse breakdown*. If the reverse-bias voltage is sufficiently large, the insulating properties of the diode break down and the diode conducts.

In the forward region, the voltage at which the current starts to increase rapidly is called the diode’s knee voltage (*VK*). The knee voltage equals the barrier potential. The knee voltage of a silicon diode is define as:

*VK*≈0.7 V.

Even though germanium diodes are rarely used in new designs, you may still encounter germanium diodes in special circuits or in older equipment. For this reason, remember that the knee voltage of a germanium diode is approximately 0.3 V.

As we will see, this unusual behavior allows us to use the diode for many purposes, but it also complicates the analysis of diode circuits. The simple diode circuit shown in Fig. 3.

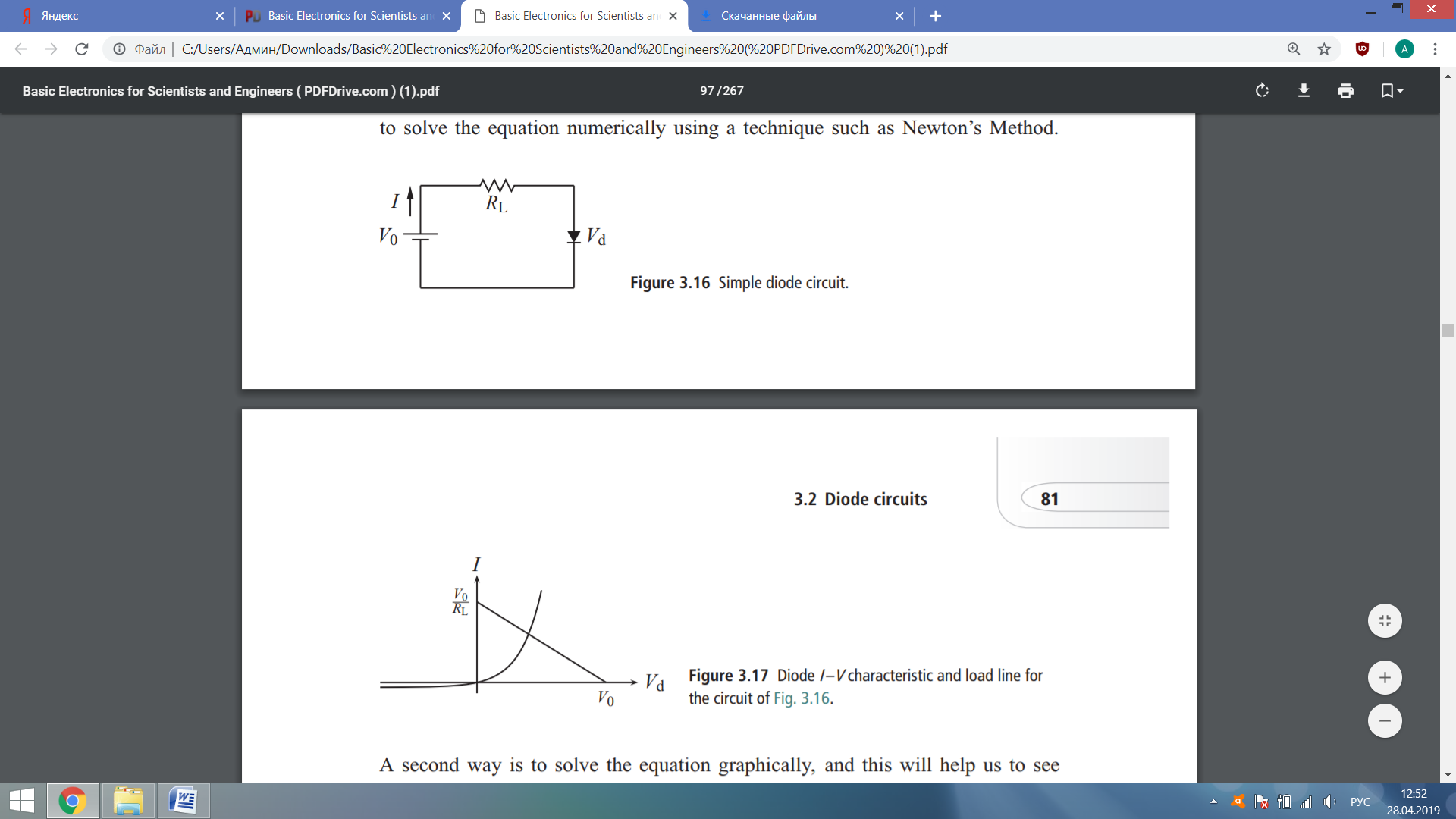


Fig. 3. Simple diode circuit

A diode is used to block the electric current flow in one direction, i.e. in forward direction and to block in reverse direction. This principle of diode makes it work as a rectifier.

The electrical properties of the semiconductor diodes are characterized by the following parameters:

- the steepness of the current-voltage characteristics for direct connection *S=*Δ*I*/Δ*U*. With increasing voltage, the steepness increases;

- the direct voltage drop *U*d, which is determined at a given forward current;

- reverse current (*Irev*) or leakage current, which is determined at a given reverse voltage close to the breakdown voltage (*Ub*). It is the current that flows through a reverse biased diode;

- direct and reverse DC resistance

*Rd=Ud/Id;*

*Rrev=Urev/Irev;*

- direct and reverse differential resistance or resistance of the diode to alternating 4 current (AC)

*Ri d=*Δ*Ud/*Δ*Id;*

*R i rev=*Δ*Urev/*Δ*Irev;*

- the power dissipation equals the product of diode voltage and current

*PD=VDID.*

- the boundary frequency characterizing the frequency properties of a semiconductor diode (*fb*);

- the maximum allowable amplitude value of the reverse voltage *Urev max*, which the diode can withstand without damage (selected by 10 – 15 % less than *Ub*). It is the maximum reverse voltage that a diode can withstand without destroying the junction;

- the maximum allowable rectified current *Ir max*;

- the maximum allowable amplitude value of the direct current *Id max*, which the diode can withstand without damage;

- the permissible operating temperature range of the environment.

I-V characteristics of rectifier diode is shown in Fig. 4.

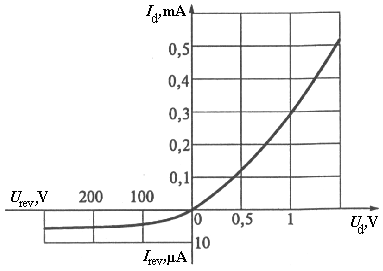


Fig.4. I-V characteristics of rectifier diode

Use the ideal diode to calculate the load voltage and load current in Fig. 1.

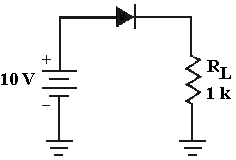


Fig. 1

*Solution*: Since the diode is forward biased, it is equivalent to a closed switch. Visualize the diode as a closed switch. Then, you can see that all of the source voltage appears across the load resistor:

*VL=10 V*.

With Ohm’s law the load current is:

*IL=10 V/1 kOm=10 mA.*

*Conclusion*: In Fig. 1, find the ideal load current if the source voltage is 5V.

*b*) A diode has a power rating of 4 W. If the diode voltage is 1.2 V and the diode current is 1.6 A, what is the power dissipation? Will the diode destroyed?

*Solution*: The power dissipation of the diode is

*PD*=(1.2V)(1.6A)=1.92 W.

This is less than the power rating, so the diode will not be destroyed.

*c*) For the current-voltage characteristic of a semiconductor diode (Fig. 2, *1* – 100 0C; *2* – 25 0C; *3* – 60 0C), determine its resistance to direct current when switched in the forward and reverse directions, if voltages are applied to the diode: *U*d= 0.6 V, *Urev* = -50 V.

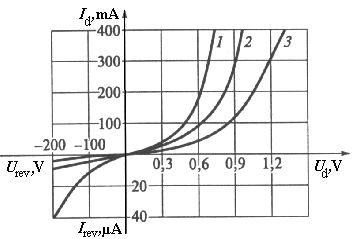


Fig. 2.

*Solution*:





**Summary:**

* A *semiconductor diode* is a device having a p-n junction mounted in a container, suitable for conducting and dissipating the heat generated in operation and having connecting leads.
* A *p-n junction* is a piece of semiconductor material in which part of the material is p-type and part is n-type.
* A diode is a nonlinear device. The knee voltage equals the barrier potential. The knee voltage of a silicon diode is define as *VK*≈0.7 V.
* The electrical properties of the semiconductor diodes are characterized by the following parameters: the steepness of the current-voltage characteristics for direct connection (*S)*; the direct voltage drop (*U*d); reverse current (*Irev*), the breakdown voltage (*Ub*); direct *Rd* and reverse *Rrev* DC resistance; the power dissipation (*PD);*  the boundary frequency (*fb*); the maximum allowable rectified current *Ir max*; the maximum allowable amplitude value of the direct current *Id max*; the permissible operating temperature range of the environment.

**Questions**

1. Draw the graphic symbol of crystal diode and explain its significance. How the polarities of crystal diode are identified?

2. How will you determine them from the I-V characteristic of a crystal diode?

3. Draw the diode curve and explain the different parts of it.

4. How to change the slope of the current-voltage characteristics of a semiconductor diode with increasing forward voltage?

5. In the most basic terms, describe what a diode acts like when it is reverse biased.

6. What is the difference between typical knee voltage of a germanium diode and a silicon diode?

7. For a diode to be useful, how much larger should the reverse resistance be than the forward resistance?

8. Why are diodes not operated in the breakdown region in rectifier service?

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**Theme 2:** **Oscillatory systems**

*Question:*

*1. Parameters of the oscillating circuit.*

*2. Serial oscillating circuit.*

*3. Parallel oscillating circuit.*

*4. Associated oscillatory circuits.*

The oscillatory circuit consists of a coil and capacitor. In addition, it can also contain a resistor (an element with a variable resistance). The inductor (or solenoid, as it is sometimes called) is a rod on which several layers of winding are wound, which, as a rule, is a copper wire. It is this element that creates oscillations in the oscillatory circuit. The rod in the middle is often called the throttle, or core, and the coil is sometimes called the solenoid.

The coil of the oscillating circuit creates oscillations only if there is a stored charge. When passing current through it, it accumulates a charge, which then gives into the circuit if the voltage drops.

Coil wires usually have very small resistance, which is always constant. In the circuit of the oscillatory circuit, the voltage and current intensity change very often. This change is subject to certain mathematical laws:

*U = U0 · cos (w · (t-t0),*

where

U is the voltage at a given time t,

U0 - the voltage at time t0,

w is the frequency of electromagnetic oscillations.

Another integral component of the circuit is electric condenser. This is an element consisting of two plates, which are separated by a dielectric. The thickness of the layer between the plates is less than their dimensions. This design allows you to accumulate on the dielectric electric charge, which can then be given in a chain.

The difference between a capacitor and a battery is that in It does not transform substances under the influence of an electric current, but there is a direct accumulation of a charge in an electric field. Thus, with the help of a capacitor it is possible to accumulate a sufficiently large charge, which can be sent all at once. At the same time, the current strength in the circuit greatly increases.

So, the oscillatory circuit consists of one more element: the resistor. This element has a resistance and is designed to control the current and voltage in the circuit. If at a constant voltage increase the resistance of the resistor, then the current will decrease in Ohm's law:

I = U / R,

where

I is the amperage,

U is the voltage,

R is the resistance.

Let's take a closer look at all the subtleties of work coil and better understand its function in the oscillatory circuit. As we have already said, the resistance of this element tends to zero. Thus, when connected to a DC circuit, a short circuit would occur. However, if you connect the coil to an alternating current circuit, it works properly. This allows us to conclude that the element provides resistance to alternating current.

But why it happens and how it a rises resistance at alternating current? To answer this question, we need to address to such a phenomenon as self-induction. When the current passes through the coil, an electromotive force (EMF) appears in it, which creates an obstacle to the change in current. The magnitude of this force depends on two factors: the inductance of the coil and the derivative of the current with respect to time. Mathematically, this dependence is expressed in terms of the equation:

*E = -L \* I "(t),*

where

E is the EMF value,

L is the inductance value of the coil (for each coil it is different and depends on the number of winding coils and their thickness),

I "(t) is the derivative of the current with respect to time (the rate of change of the current strength).

The strength of the direct current does not change with time, therefore resistance does not arise when it acts.

But with alternating current, all its parameters constantly vary in sinusoidal or cosine law, resulting in an EMF that prevents these changes. This resistance is called induction and is calculated by the formula:

*XL = w · L,*

where

w is the oscillation frequency of the circuit,

L - coil inductance.

The current strength in the solenoid increases linearly and decreases under various laws. This means that if you stop supplying current to the coil, it will continue to charge for a while in the circuit. And if at the same time abruptly interrupt the supply of current, there will be a blow due to the fact that the charge will try to dispense and exit the coil. This is a serious problem in industrial production. Such an effect (although not entirely related to the oscillatory circuit) can be observed, for example, when pulling the plug from the socket. At the same time, a spark leaps, which on such a scale is not capable of harming a person. It is due to the fact that the magnetic field does not disappear immediately, but gradually dissipates, inducing currents in other conductors. On industrial scale, the current is many times greater than the usual 220 volts, so when the circuit is interrupted, sparks of such intensity may appear in the production, which will do a lot of harm to both the plant and the person.

The whole cycle of the oscillating circuit can be divided into two parts. Now we will examine in detail the processes occurring in each part.

* *First phase:* positive capacitor plate starts to discharge, giving current to the circuit. At this moment, the current goes from a positive charge to a negative one, passing through a coil. As a result, electromagnetic oscillations occur in the circuit. The current, passing through the coil, transfers to the second plate and charges it positively (whereas the first plate with which the current was flowing is negatively charged).
* *Second phase:* there is a direct reverse process. The current passes from the positive plate (which at the very beginning was negative) to the negative, passing through the coil again. And all the charges fall into place.

The cycle is repeated until the capacitor will charge. In an ideal oscillatory circuit, this process is infinite, and in real energy losses are unavoidable due to various factors: heating, which occurs due to the existence of resistance in the circuit (Joule heat), and the like

In addition to simple "coil-capacitor" circuits (Fig. 1) and "Coil-resistor-capacitor", there are other options that use as the basis the oscillating circuit. This, for example, is a parallel circuit, which is distinguished by the fact that it exists as an element of an electrical circuit (because, if it existed separately, it would be a sequential circuit, which was discussed in the article).

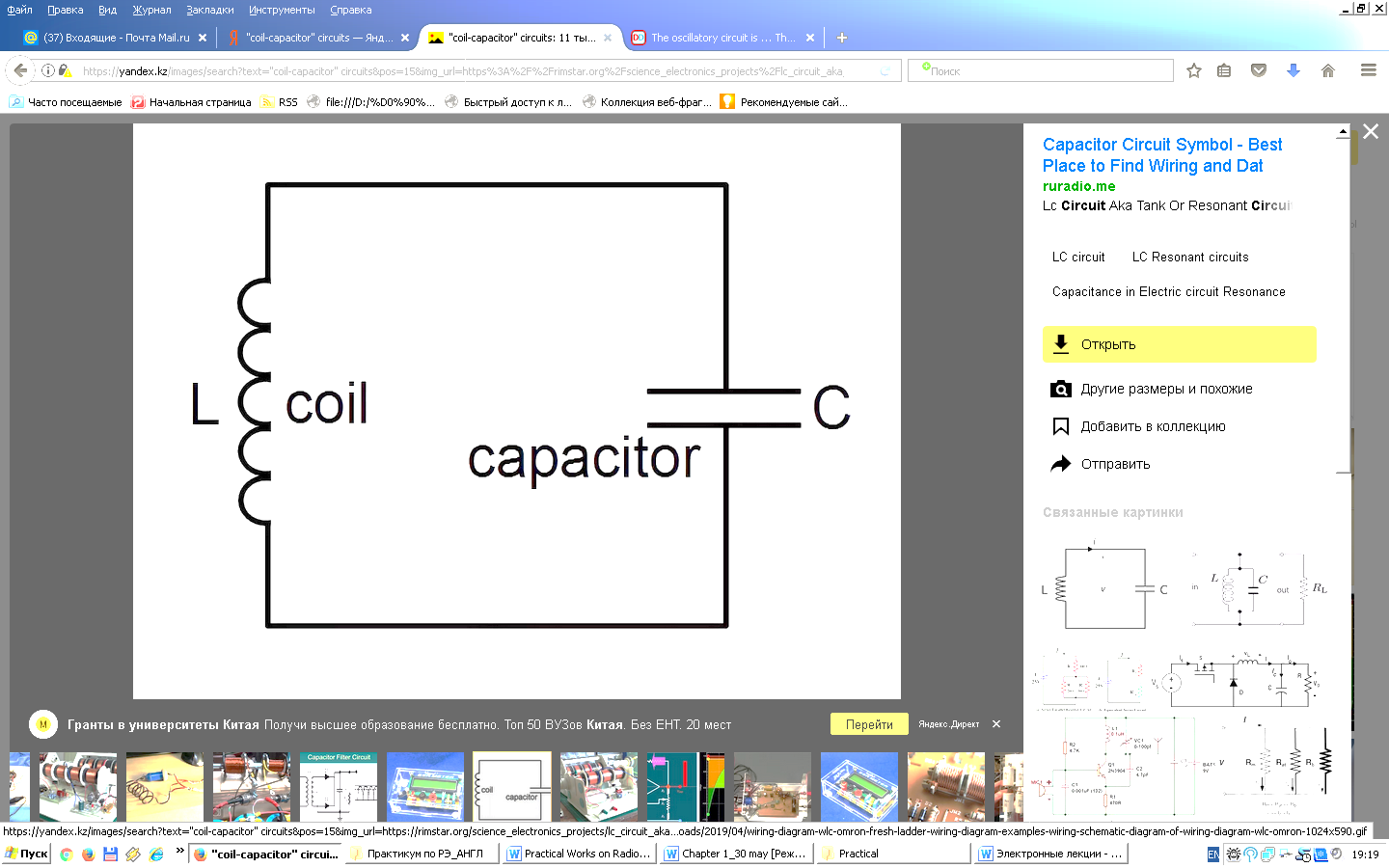


Fig. 1

There are also other types of designs including various electrical components. For example, you can connect a transistor to the network, which will open and close the circuit with a frequency equal to the oscillation frequency in the circuit. Thus, undamped oscillations will be established in the system

The most familiar use of components circuits are electromagnets. They, in turn, are used in intercoms, electric motors, sensors and in many other not so ordinary areas. Another application is an oscillator. In fact, this use of the circuit is very familiar to us: in this form, it is used in the microwave to create waves, and in mobile and radio communications to transmit information over a distance. All this is due to the fact that the oscillations of electromagnetic waves can be encoded in such a way that it becomes possible to transmit information over long distances.

The inductance itself can be used as an element of the transformer: two coils with different numbers of windings can transmit their charge using the electromagnetic field. But since the characteristics of the solenoids are different, the current indicators in the two circuits to which these two inductances are connected will differ. Thus, it is possible to convert a current with a voltage of, say, 220 volts into a current with a voltage of 12 volts.

We have analyzed the working principle in detail. Oscillatory circuit and each part of it separately. We learned that an oscillating circuit is a device designed to create electromagnetic waves. However, these are only the foundations of the complex mechanics of these seemingly simple elements. Learn more about the intricacies of the contour and its components can be from the specialized literature.

An electrical circuit is connected as a series circuit or a parallel circuit. In a series circuit, the current is the same throughout every part of the circuit. In a parallel circuit, the voltage is the same for each individual branch. Ohm’s Law gives a simple equation that can help you calculate the voltage, current and resistance of a parallel circuit.

The voltage is the same for each resistor in a parallel circuit because there are only two electrically common points, and the voltage between common points is always the same. Voltage, or the electric potential difference, is the energy per unit charge; it is measured in volts on a voltmeter.

Electric current can take multiple paths through a parallel circuit. The total current is equal to the sum of each branch’s individual current. The circuit’s total current can be calculated with the equation

*I = V/(1/R1 + 1/R2 + ... + 1/Rn),*

where *I* is the total current, *V* is the voltage and *R1, R2* and so on are the resistance of each individual branch. Current is measured in amperes with an ammeter.

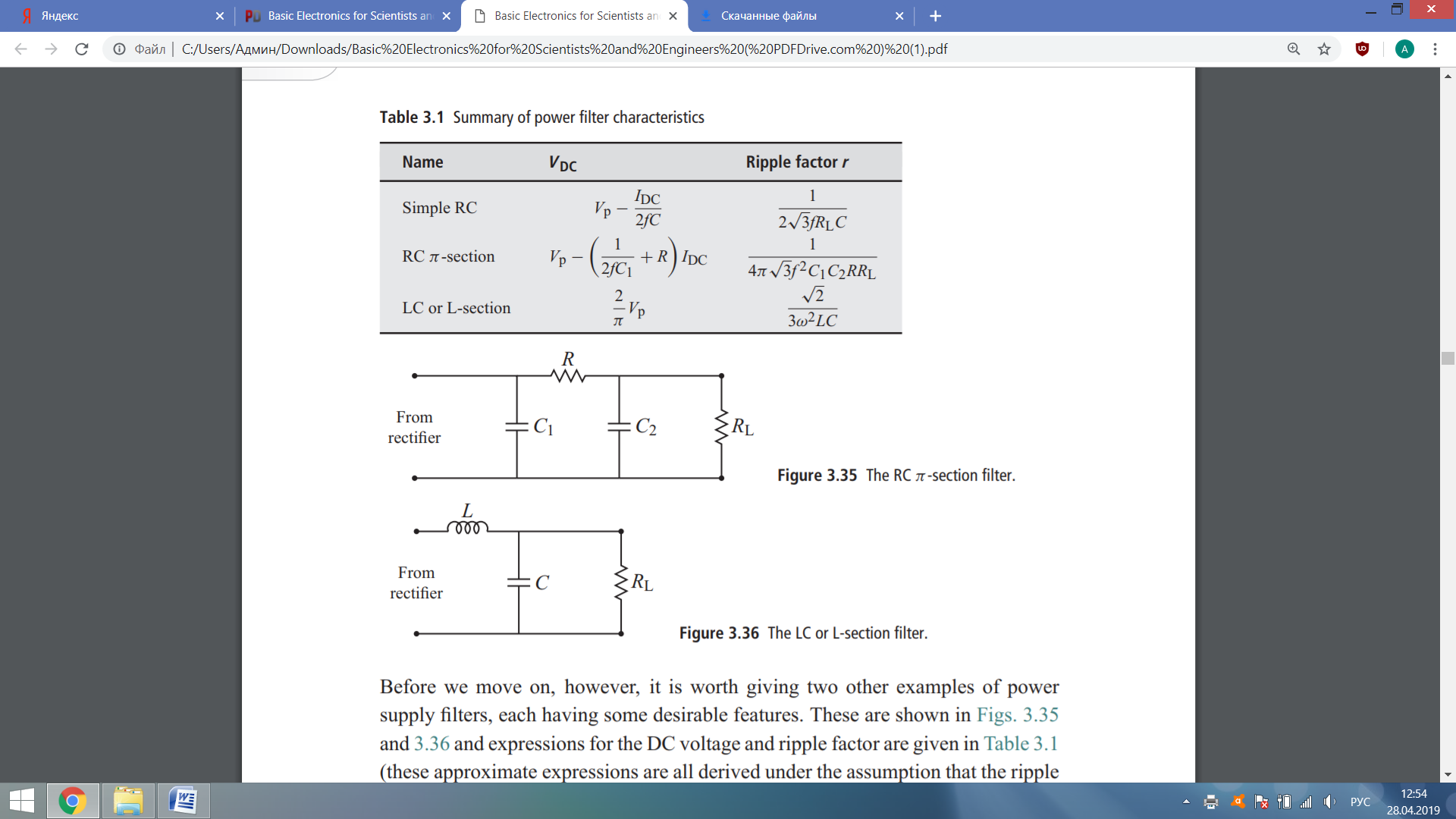
The total resistance for the parallel circuit must be less than the resistance of any individual branch. Resistance is measured in ohms. Calculate the total resistance by dividing the total current from the voltage; this equation, *I = V/R*, is known as Ohm’s Law. It can be rewritten as *R = V/I*. For example, a parallel circuit with 14 volts and 2 amps has a total resistance of 14/2, or 7 ohms. If you do not know the total voltage and current, calculate the total resistance from the individual branch’s resistances with the equation

*1/R = 1/R1 + 1/R2 + 1/R3 + ... + 1/Rn.*

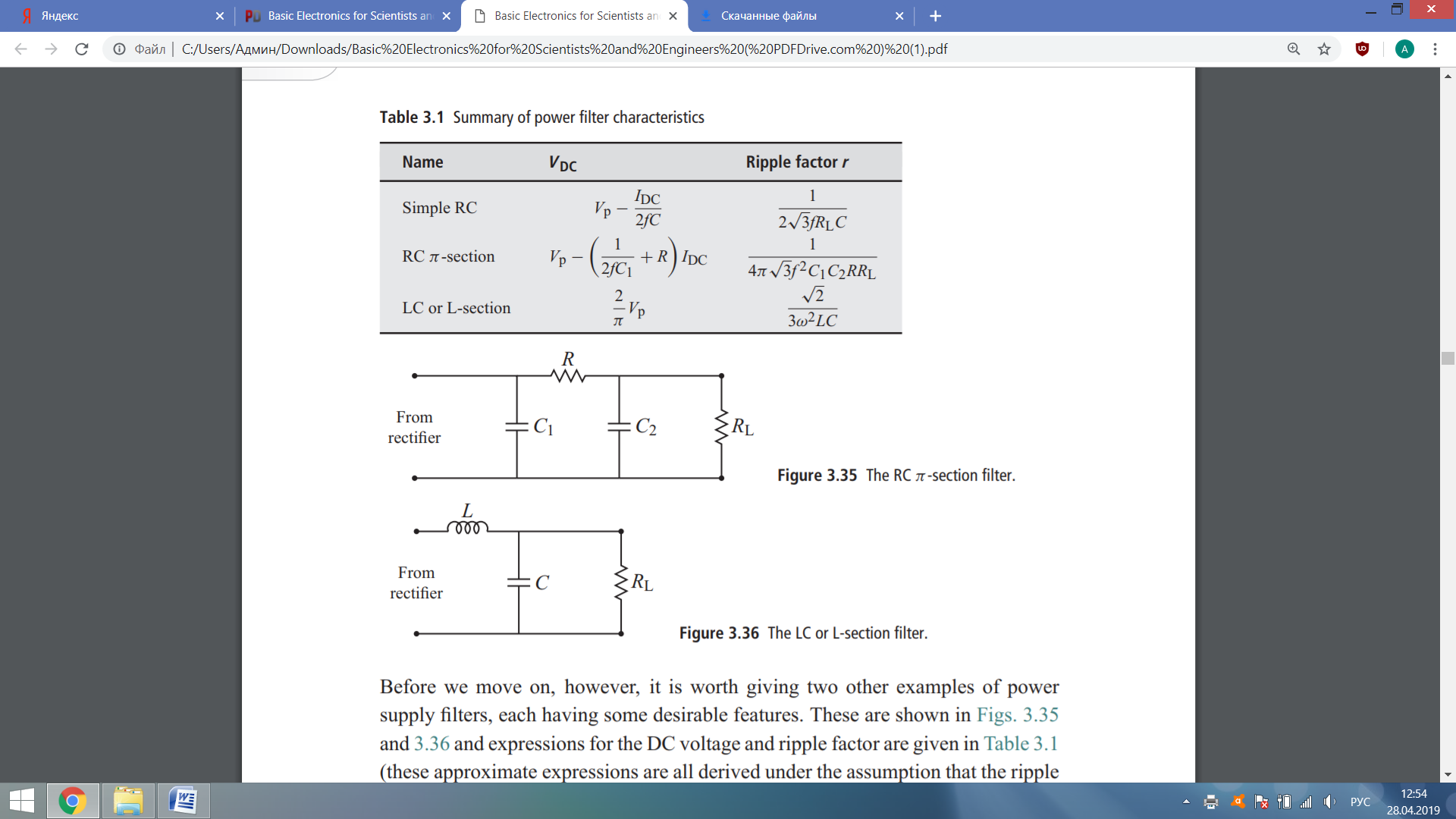
An individual branch opening stops only the current in that branch. The rest of the branches will continue to work because the current has multiple paths it can take across the circuit.

Tasks:

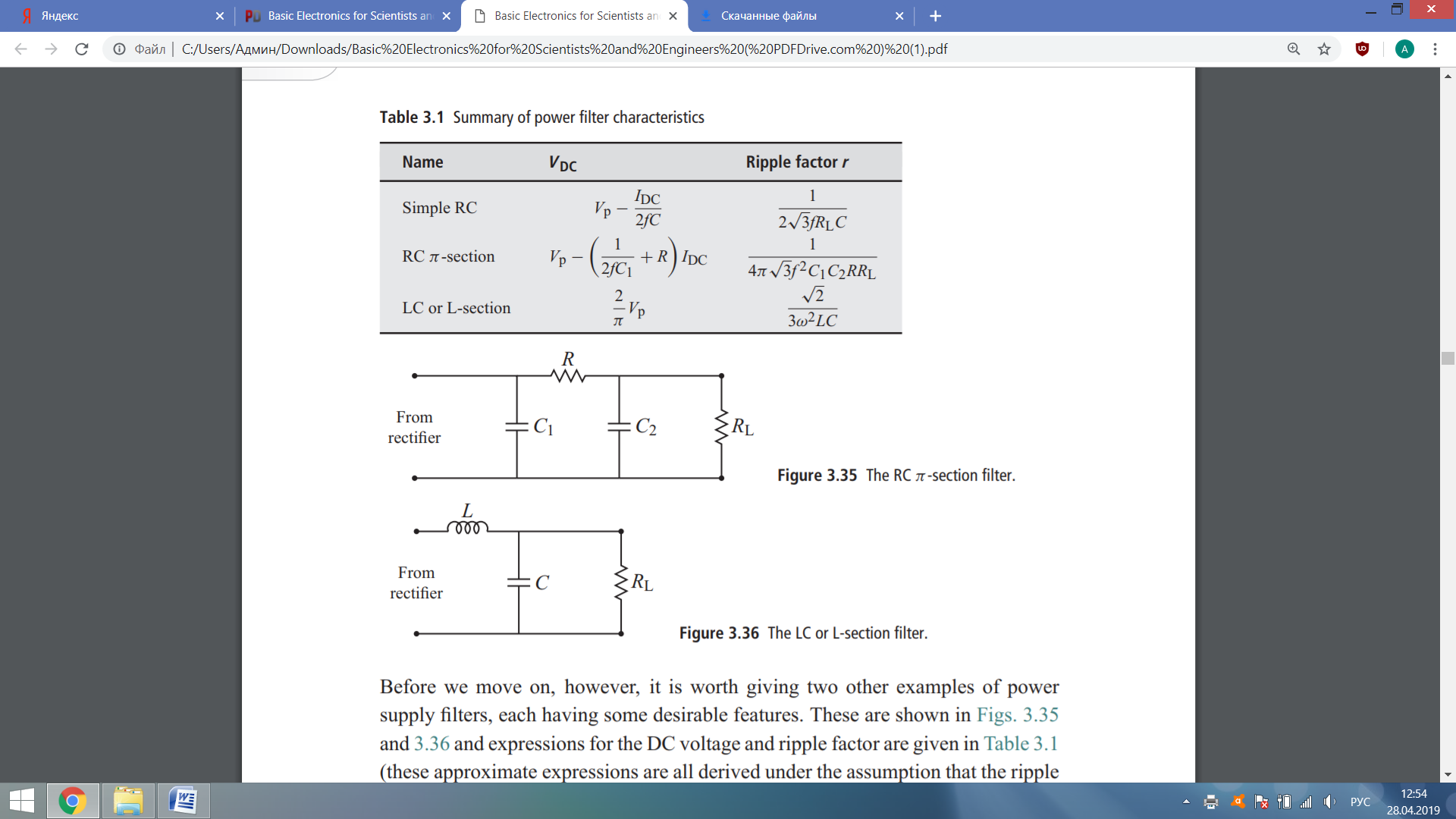
1. Explain the following characteristics: summary of power filter characteristics.



2. Explain the principle of the following scheme (RC - π section filter):



3. Explain the principle of the following scheme (LC or L–section filter):



Literature:

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**Theme 3: Antennas and radio propagation**

*Question:*

## *Basic Types of Antennas*

1. *Radiation Mechanism*
2. *Antenna Characteristics*

An Antenna is a transducer, which converts electrical power into electromagnetic waves and vice versa.

An Antenna can be used either as a transmitting antenna or a receiving antenna.

* A transmitting antenna is one, which converts electrical signals into electromagnetic waves and radiates them.
* A receiving antenna is one, which converts electromagnetic waves from the received beam into electrical signals.
* In two-way communication, the same antenna can be used for both transmission and reception.

Antenna can also be termed as an Aerial. Plural of it is, antennae or antennas. Nowadays, antennas have undergone many changes, in accordance with their size and shape. There are many types of antennas depending upon their wide variety of applications.

Following pictures are examples of different types of Antennas.

## *Radiation Mechanism.* The sole functionality of an antenna is power radiation or reception. Antenna (whether it transmits or receives or does both) can be connected to the circuitry at the station through a transmission line. The functioning of an antenna depends upon the radiation mechanism of a transmission line.

A conductor, which is designed to carry current over large distances with minimum losses, is termed as a transmission line. For example, a wire, which is connected to an antenna. A transmission line conducting current with uniform velocity, and the line being a straight one with infinite extent, radiates no power.

For a transmission line, to become a waveguide or to radiate power, has to be processed as such.

* If the power has to be radiated, though the current conduction is with uniform velocity, the wire or transmission line should be bent, truncated or terminated.
* If this transmission line has current, which accelerates or decelerates with a timevarying constant, then it radiates the power even though the wire is straight.
* The device or tube, if bent or terminated to radiate energy, then it is called as waveguide. These are especially used for the microwave transmission or reception.

This can be well understood by observing the following diagram on Fig. 1.

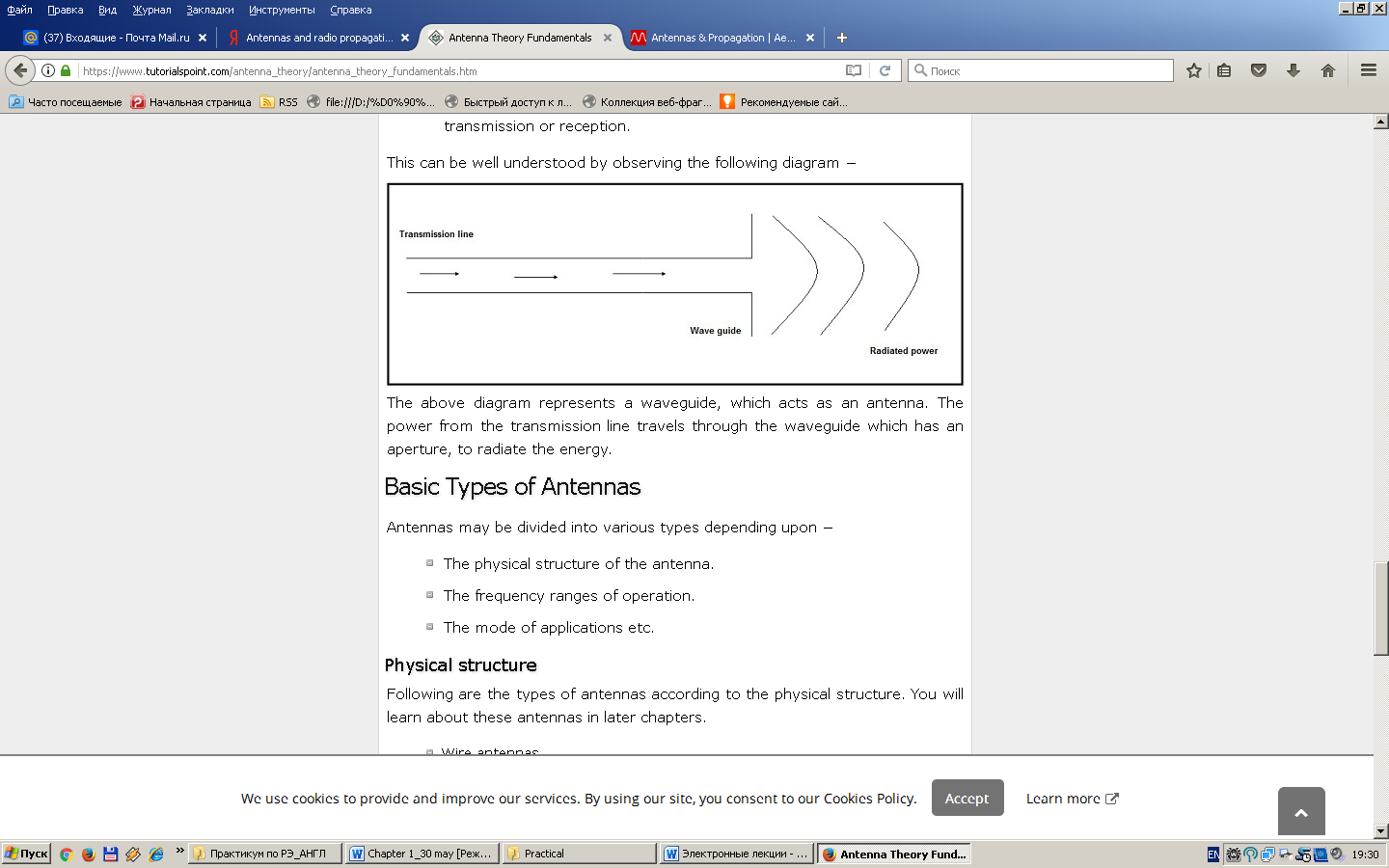


Fig. 1

The above diagram represents a waveguide, which acts as an antenna. The power from the transmission line travels through the waveguide which has an aperture, to radiate the energy.

Antennas may be divided into various types depending upon:

* The physical structure of the antenna.
* The frequency ranges of operation.
* The mode of applications etc.

Following are the types of antennas according to the physical structure. You will learn about these antennas in later chapters.

* Wire antennas
* Aperture antennas
* Reflector antennas
* Lens antennas
* Micro strip antennas
* Array antennas

Following are the types of antennas according to the frequency of operation.

* Very Low Frequency (VLF)
* Low Frequency (LF)
* Medium Frequency (MF)
* High Frequency (HF)
* Very High Frequency (VHF)
* Ultra High Frequency (UHF)
* Super High Frequency (SHF)
* Micro wave
* Radio wave

Following are the types of antennas according to the modes of applications −

* Point-to-point communications
* Broadcasting applications
* Radar communications
* Satellite communications

Antennas have to be classified to understand their physical structure and functionality more clearly. There are many types of antennas depending upon the applications applications.

|  |  |  |
| --- | --- | --- |
| **Type of antenna** | **Examples** | **Applications** |
| Wire Antennas | Dipole antenna, Monopole antenna, Helix antenna, Loop antenna | Personal applications, buildings, ships, automobiles, space crafts |
| Aperture Antennas | Waveguide (opening), Horn antenna | Flush-mounted applications, air-craft, space craft |
| Reflector Antennas | Parabolic reflectors, Corner reflectors | Microwave communication, satellite tracking, radio astronomy |
| Lens Antennas | Convex-plane, Concave-plane, Convex-convex, Concaveconcave lenses | Used for very high frequency applications |
| Micro strip Antennas | Circular-shaped, Rectangular shaped metallic patch above the ground plane | Air-craft, space-craft, satellites, missiles, cars, mobile phones etc. |
| Array Antennas | Yagi-Uda antenna, Micro strip patch array, Aperture array, Slotted wave guide array | Used for very high gain applications, mostly when needs to control the radiation pattern |

Let us discuss the above-mentioned types of antennas in detail, in the coming chapters.

*Antenna Characteristics.* The radiation pattern of an antenna is a graphical representation of the radiation properties of the antenna. Graphically, we surround the antenna by a sphere and evaluate the electric / magnetic fields (far field radiation fields) at a distance equal to the radius of the sphere on Fig. 1.

Usually we will focus on one field component (*Eff* or *Hff*) radiated by the antenna. Usually we plot the dominant component of the E-field (e.g. *E*θ for a dipole). This can be done by plotting the field component over all angles (*θ,φ*), yielding a 3D plot.

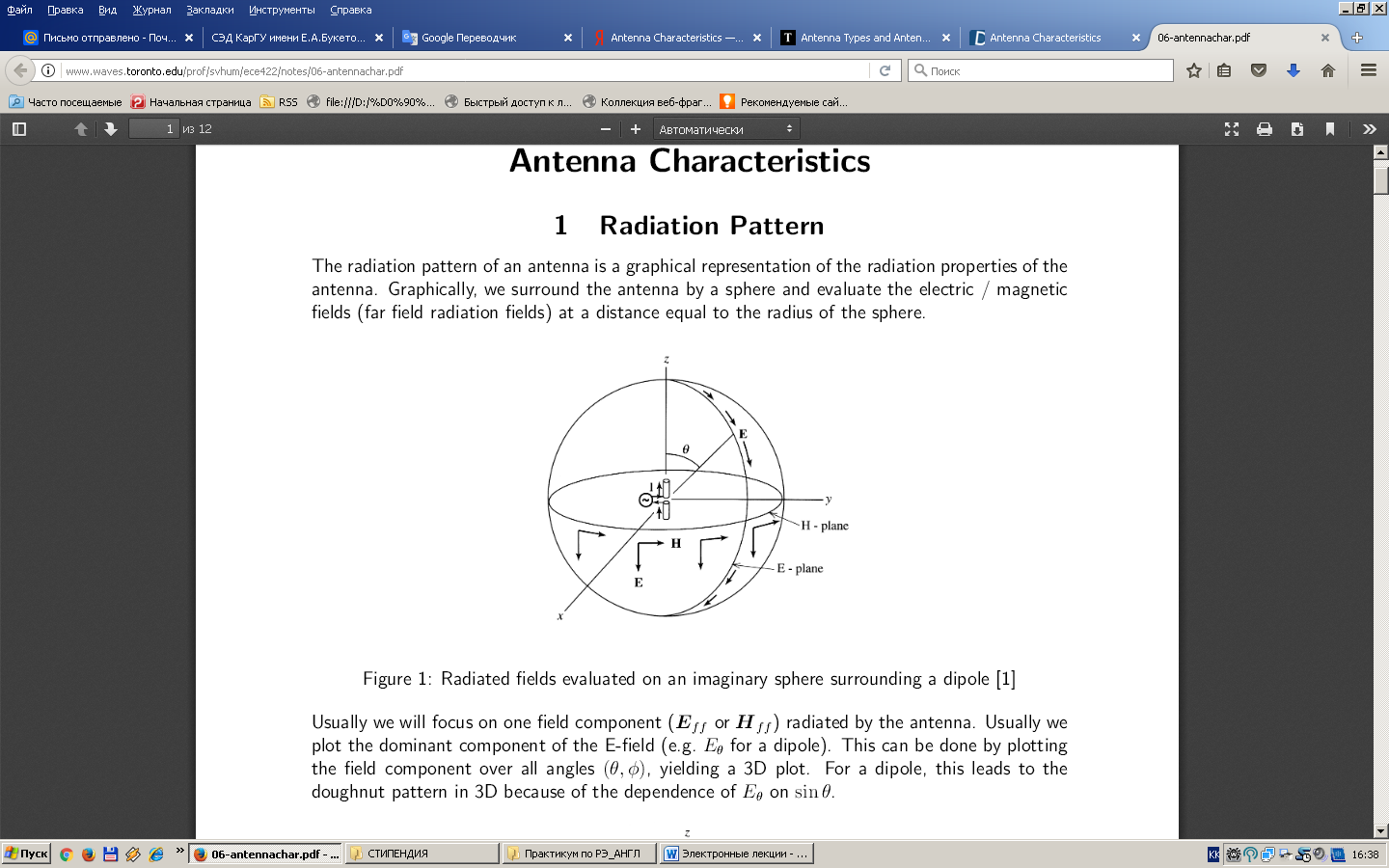


Fig. 1

For a dipole, this leads to the doughnut pattern in 3D because of the dependence of *E*θ on sin*θ* (Fig. 2).

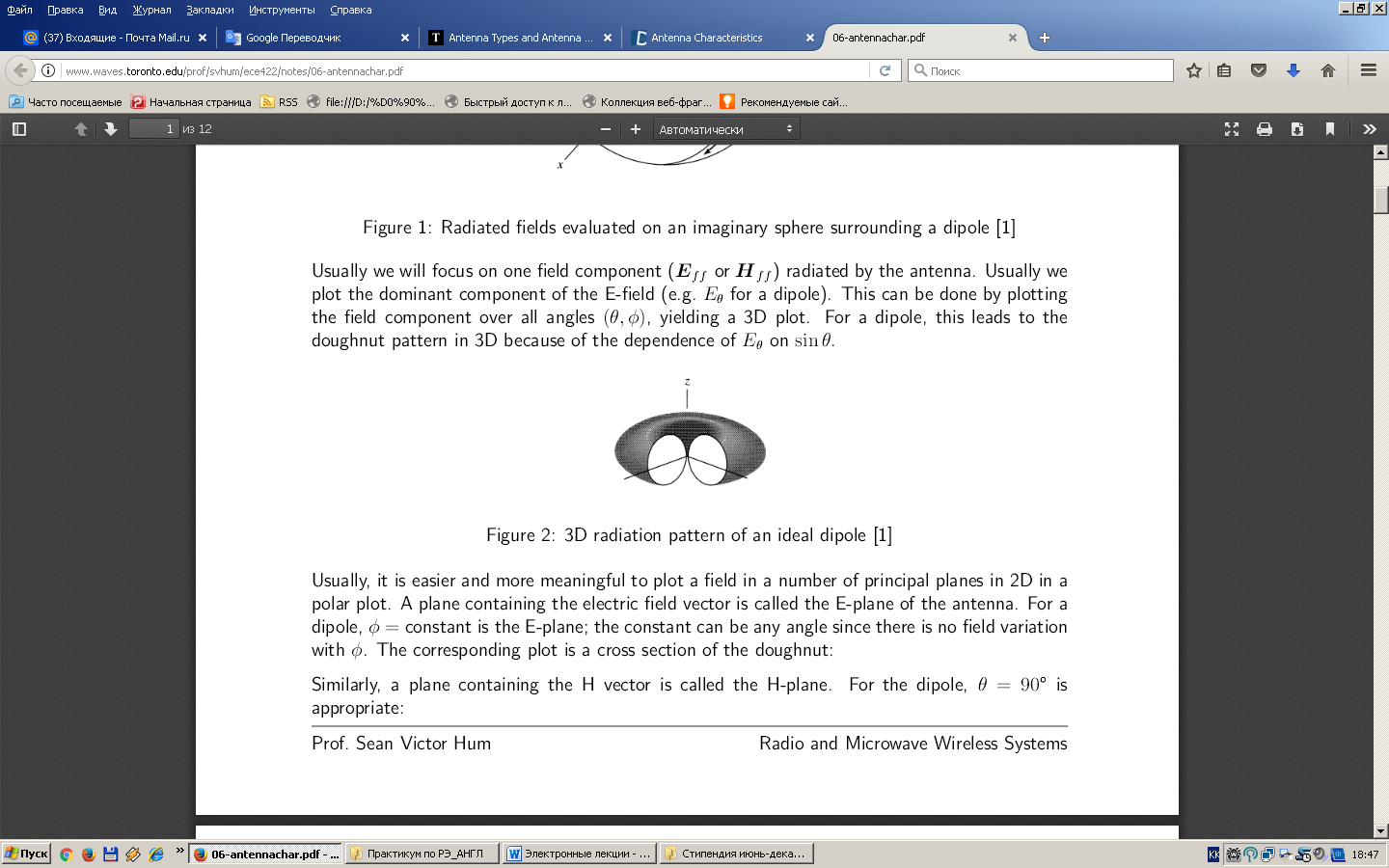


Fig. 2

Usually, it is easier and more meaningful to plot a field in a number of principal planes in 2D in a polar plot. A plane containing the electric field vector is called the E-plane of the antenna. For a dipole, φ =constant is the E-plane; the constant can be any angle since there is no field variation with φ. The corresponding plot is a cross section of the doughnut.

Similarly, a plane containing the H vector is called the H-plane. For the dipole, θ= 90◦ is appropriate.

Since there is no variation of the radiated E/H fields with azimuth angle (φ), we call this type of antenna pattern omnidirectional 1.

Often, we will plot the normalized field pattern, which has a maximum value of 1. In general, it is denoted F(θ,φ) and obviously depends on both angles in the spherical coordinate system. For an ideal dipole, it is defined as

*F(θ) =Eθ /max(Eθ)= sin θ*. (1)

We can also plot the normalized power pattern |*F(θ,φ)|*2 of an antenna, which is useful for defining a number of parameters. Refer to Figure 3, which shows an example of a normalized power pattern in 3D form and also in a slice on a rectilinear plot. A few interesting features are observable:

•Minor lobes, which are any lobes other than the main lobe in the pattern, which includes sidelobes and back lobes. They are generally undesirable since radiation in the sidelobes reduces power radiated in the desired direction.

•When characterizing the main lobe, it is possible to quantify it according to its half-power beamwidth (HPBW), which is analogous to the half-power bandwidth (-3 dB point) we are used to finding for filters, except that it is for spatial angles.

•Similarly, another important parameter about the radiation pattern is the first null beamwidth (FNBW), which is the angular spread between the first two nulls in the pattern.

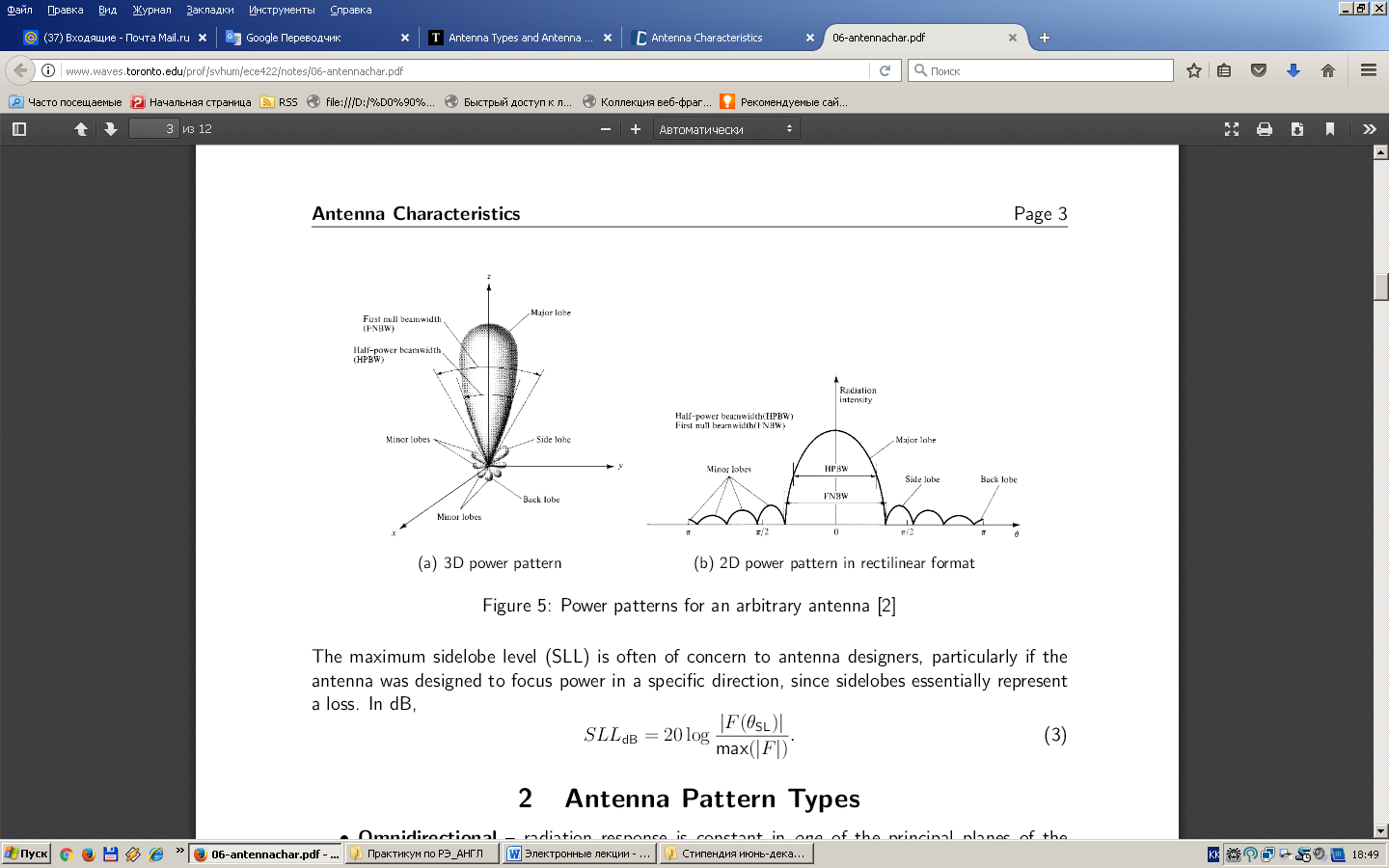


Fig. 3

Very often we will plot antenna patterns in dB, which is inherently a power plot. This can be used to extract fine features of the antenna pattern on a logarithmic scale.

*F(θ,φ)|dB= 20 log|F(θ,φ)|= 10 log|F(θ,φ)|2* (2)

The maximum sidelobe level (SLL) is often of concern to antenna designers, particularly if the antenna was designed to focus power in a specific direction, since sidelobes essentially represent a loss. In dB,

 (3)

Antenna Pattern Types are:

• Omnidirectional – radiation response is constant in one of the principal planes of the antenna.

• Isotropic – antenna radiates equally in all directions in 3D space; theoretically impossible to realize, but a useful reference for quantifying how directive real antennas are.

• Broadside – main beam is normal to the plane or axis containing the antenna. An example for an antenna oriented along the z-axis is shown in Figure 4(a).

• Endfire – main beam is in the plane or parallel to the axis containing the antenna. An example for an antenna oriented along the z-axis is shown in Figure 4(c).

Question:

1. What conductor is called a symmetrical vibrator?

2. What changes occur in the radio waves when interacting with the propagation medium?

3. At which frequencies is the most stable relationship?

4. List the benefits of directional antennas.

5. On which waves is fading observed?

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**Theme 4:** **Amplifiers**

*Question:*

*1. Parameters and characteristics of amplifiers.*

*2. Amplifiers on a bipolar transistor.*

*3. Field-effect transistor amplifier.*

*4. Power Amplifiers.*

The term ‘operational amplifier’ (op-amp) describes an important amplifier circuit that can form the basis of audio and video amplifiers, filters, buffers, line drivers, instrumentation amplifiers, comparators, oscillators, and many other analogue circuits. The op-amp is a simple building block. It has two inputs, one is called the inverting input (often labelled minus) and the other is called the non-inverting input (often labelled plus). Usually op-amps have a single output, but special op-amps used in radio frequency circuits have two outputs. The op-amp symbol used in circuit diagrams is shown in Figure 1.

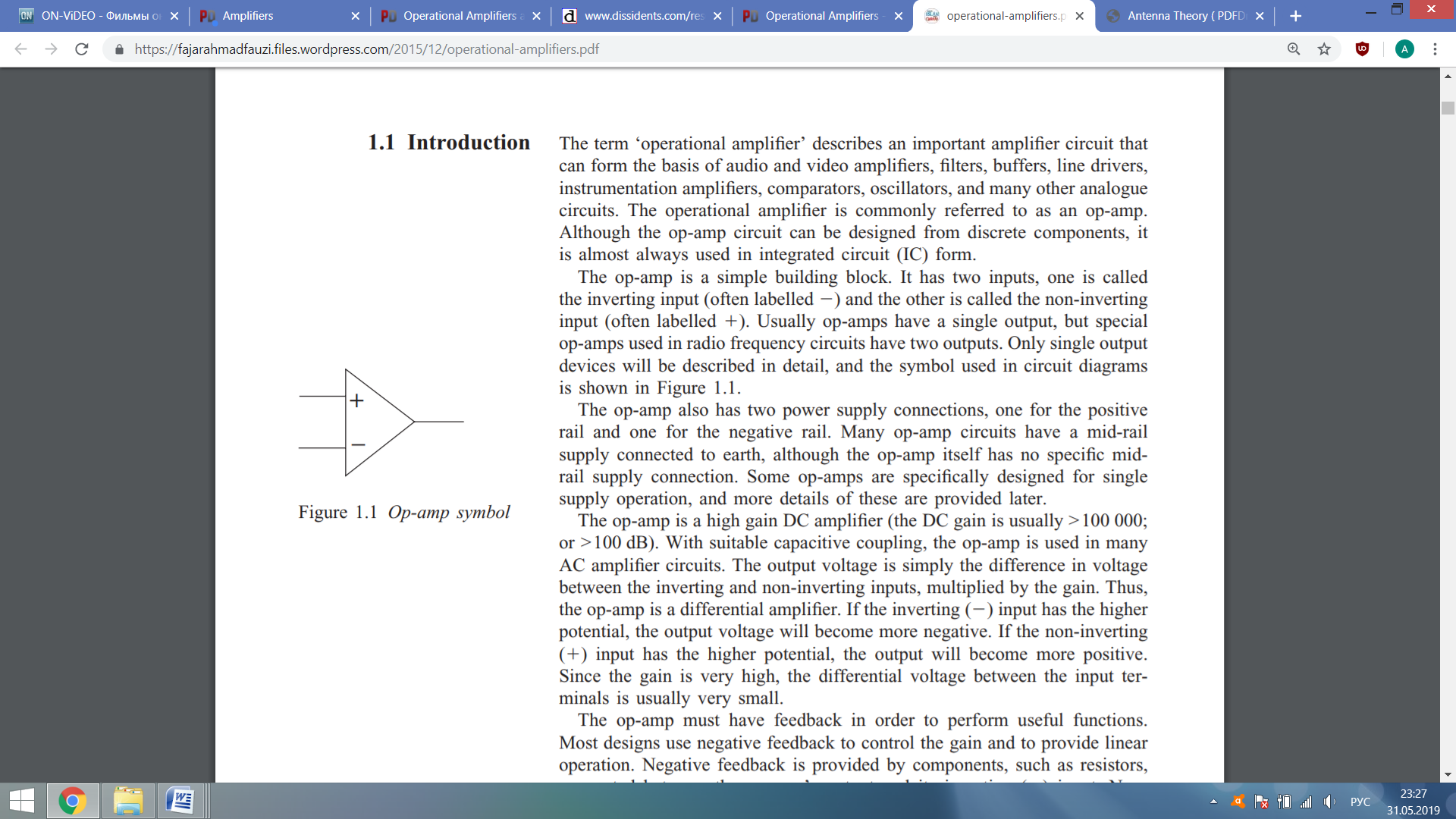


Fig. 1. Operational amplifier symbol

Let’s сonsider the parameters and characteristics of amplifiers.

*The Bode plot* is a graphical response prediction technique that is useful for both circuit design and analysis. A Bode plot is in actuality, a pair of plots: One graphs the gain of a system versus frequency, while the other details the circuit phase versus frequency. Both of these items are very important in the design of well-behaved, optimal operational amplifier circuits. Generally, Bode plots are drawn with logarithmic frequency axes, a decibel gain axis, and a phase axis in degrees. First, let’s take a look at the gain plot. A typical gain plot is shown Figure 2.

Note how the plot is relatively flat in the middle, or midband, region. The gain value in this region is known as the midband gain. At either extreme of the midband region, the gain begins to decrease. The gain plot shows two important frequencies, f1 and f2. f1 is the lower break frequency while f2 is the upper break frequency. The gain at the break frequencies is 3 dB less than the midband gain. These frequencies are also known as the half-power points, or corner frequencies. Normally, amplifiers are only used for signals between f1 and f2. The exact shape of the rolloff regions will depend on the design of the circuit. It is possible to design amplifiers with no lower break frequency (i.e., a DC amplifier), however, all amplifiers will exhibit an upper break. The break points are caused by the presence of circuit reactances, typically coupling and stray capacitances. The gain plot is a summation of the midband response with the upper and lower frequency limiting networks. Let’s take a look at the lower break, f1.

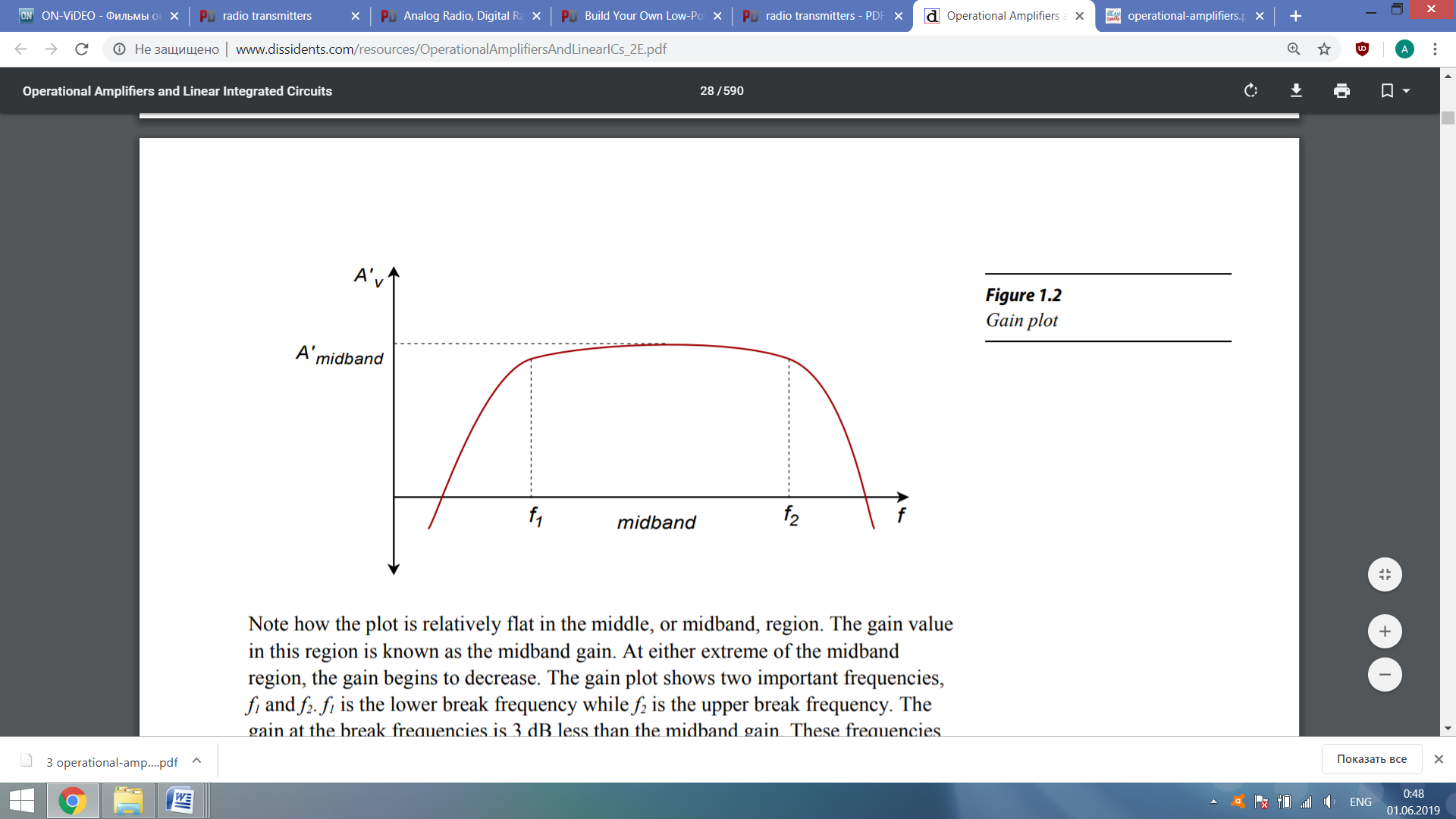
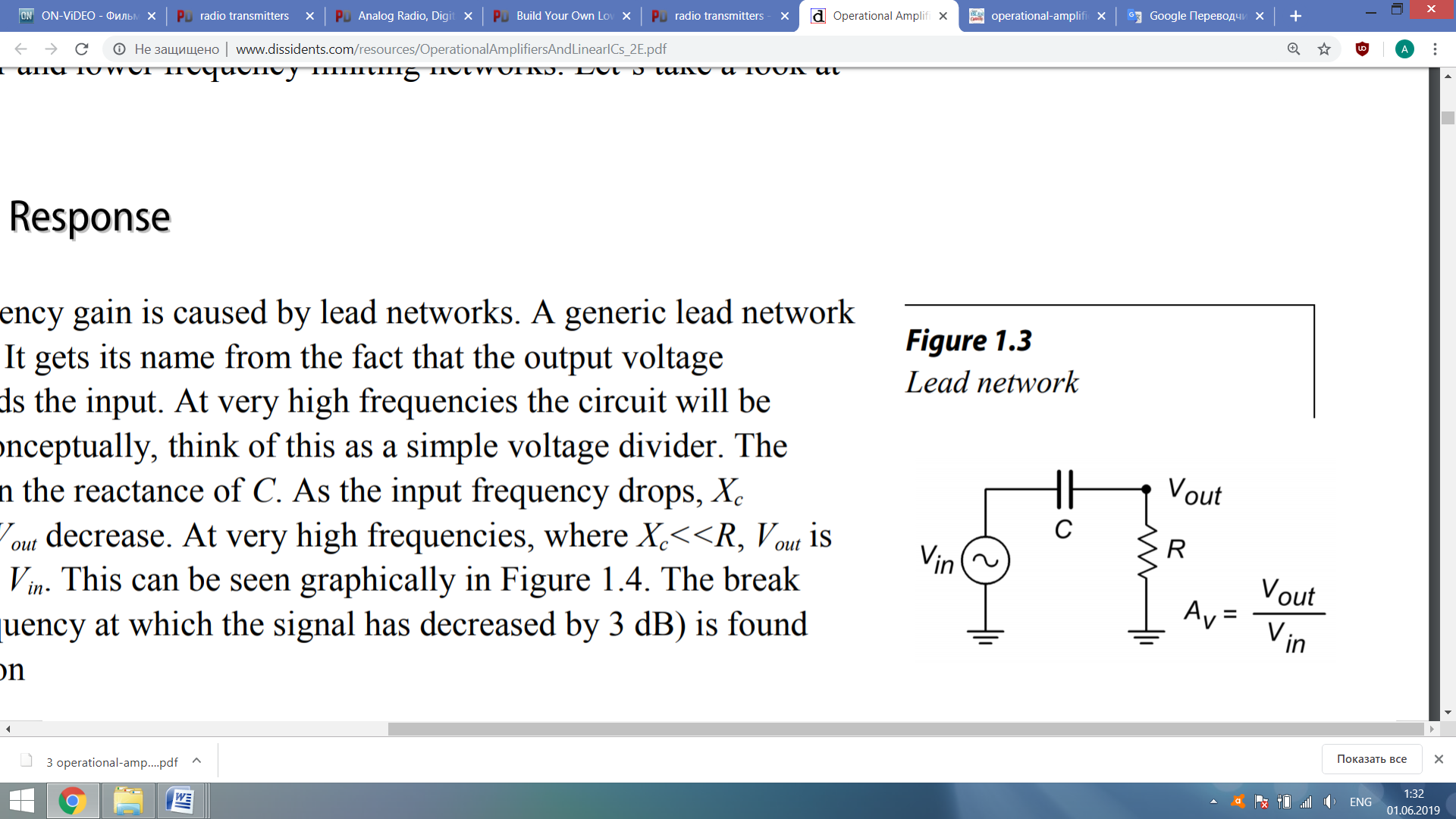
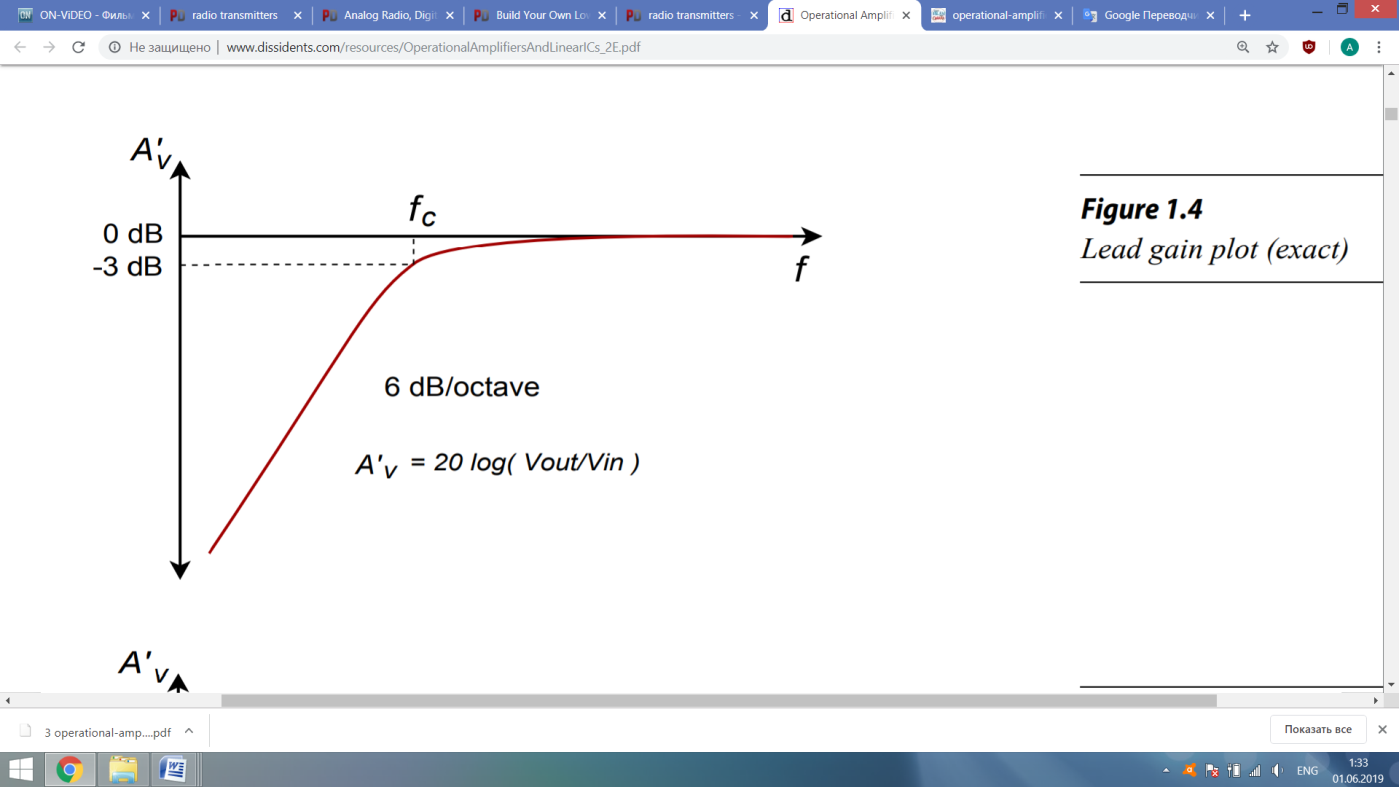


Fig. 2. Gain plot

Reduction in low frequency gain is caused by lead networks. A generic lead network is shown in Fig. 3, a. It gets its name from the fact that the output voltage developed across R leads the input. At very high frequencies the circuit will be essentially resistive. Conceptually, think of this as a simple voltage divider. The divider ratio depends on the reactance of *C*. As the input frequency drops, Xc increases. This makes Vout decrease. At very high frequencies, where Xc<<R, Vout is approximately equal to Vin. This can be seen graphically in Fig. 3, b.

a) b)

Fig. 3

The standard equation of break frequency (i.e., the frequency at which the signal has decreased by 3 dB) is



The response below fc will be a straight line if a decibel gain axis and a logarithmic frequency axis are used. This makes for very quick and convenient sketching of circuit response (Fig. 4). The decibel gain at the frequency of interest is equal to



where fc is the critical frequency, f is the frequency of interest.

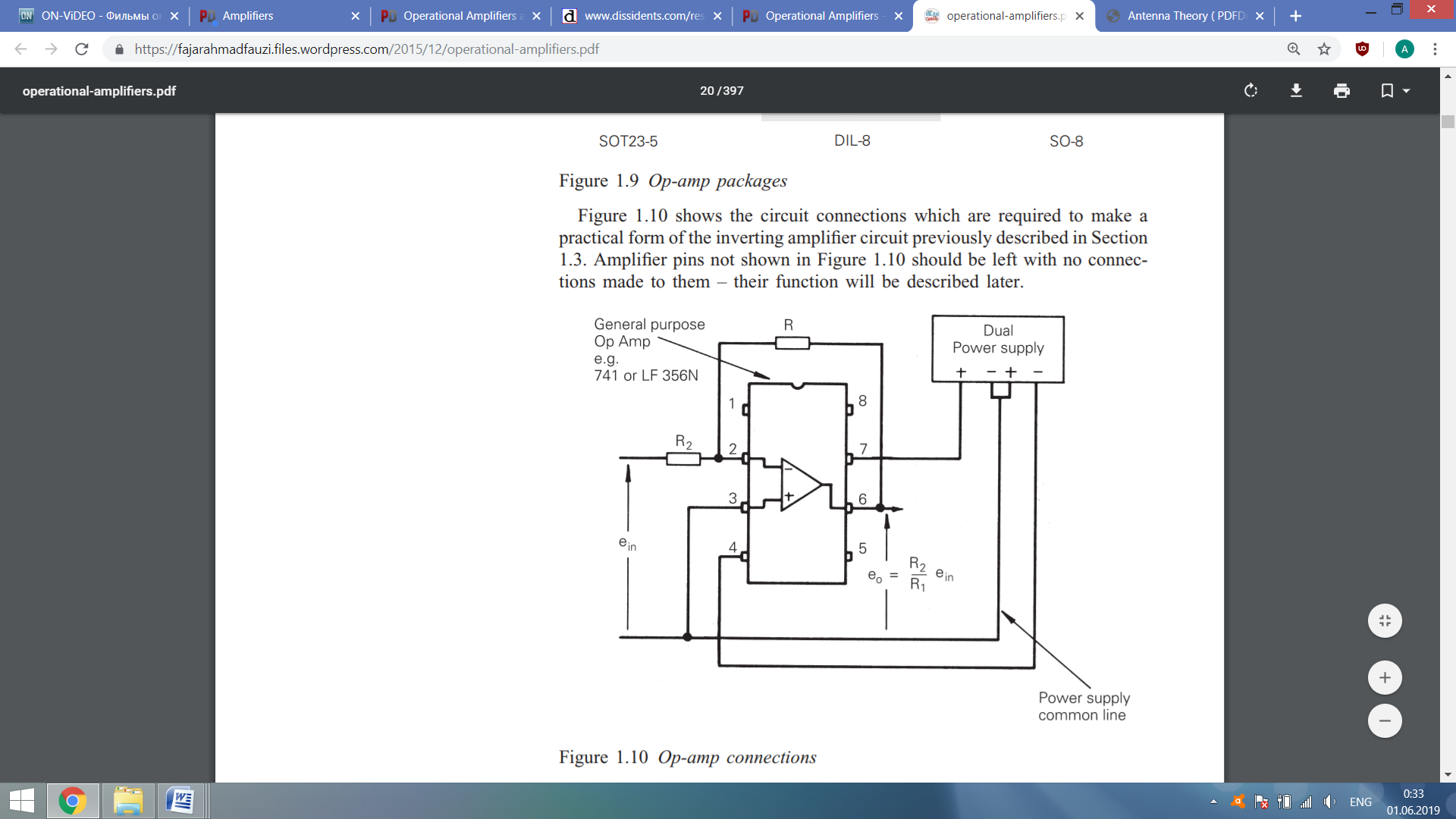


Fig. 4. Operational amplifier connections

*Example**1.1.* An amplifier has a lower break frequency of 40 Hz. How much gain is lost at 10 Hz?







In other words, the gain is 12.3 dB lower than it is in the midband. Note that 10 Hz is 2 octaves below the break frequency. Because the cutoff slope is 6 dB per octave, each octave loses 6 dB. Therefore, the approximate result is -12 dB, which double-checks the exact result. Without the lead network, the gain would stay at 0 dB all the way down to DC (0 Hz).

*Example**1.2.* Draw the Bode gain plot for the following amplifier:  midband = 26 dB, one lead network critical at 200 Hz, one lag network critical at 10 kHz, and another lag network critical at 30 kHz. The dominant lag network is 10 kHz. There is only one lead network, so it’s dominant by default.

Because an amplifier must have two input and two output terminals, a transistor used as an amplifier must have one of its three terminals common to both input and output as shown in Fig 5. The choice of which terminal is used as the common connection has a marked effect on the performance of the amplifier (Fig. 5).

A transistor connected in the three modes illustrated in Fig.5 would show quite different characteristic curves for each mode. These differences can be exploited by the circuit designer to give an amplifier with characteristics that are most suited a particular purpose. Note that the diagrams are shown here reduced to their most basic form and are not intended to be practical circuits.

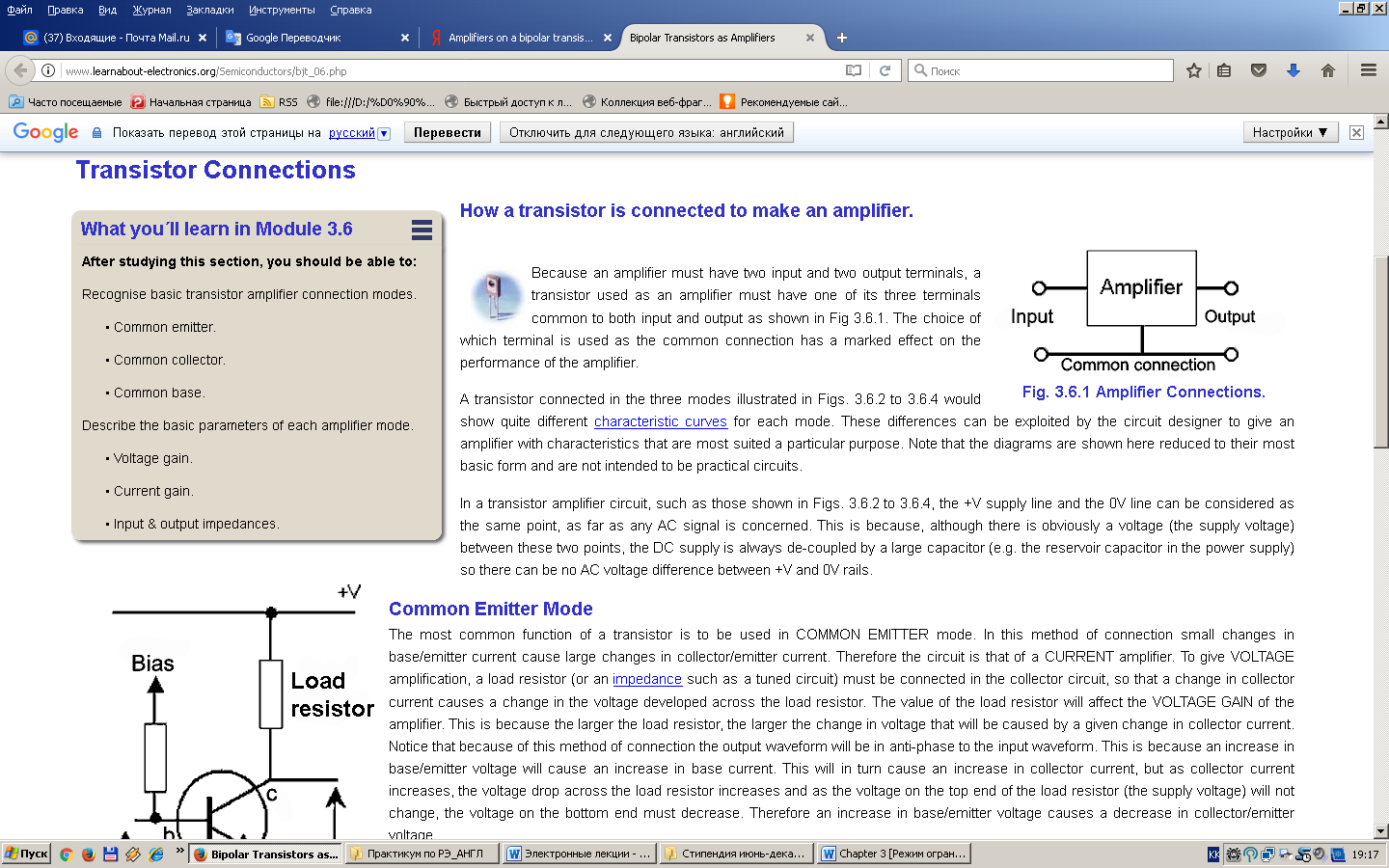


Fig. 5

In a transistor amplifier circuit, such as those shown in Fig. 5, the +V supply line and the 0V line can be considered as the same point, as far as any AC signal is concerned. This is because, although there is obviously a voltage (the supply voltage) between these two points, the DC supply is always de-coupled by a large capacitor (e.g. the reservoir capacitor in the power supply) so there can be no AC voltage difference between +V and 0V rails.

Power amplifiers are used in wireless transmitters, broadcast transmitters, and hi-fi audio equipment. The most frequently-used device for power amplification is the bipolar transistor. However, vacuum tubes, once considered obsolete, are becoming increasingly popular, especially among musicians. Many professional musicians believe that the vacuum tube (known as a "valve" in England) provides superior fidelity.

Two important considerations in power amplification are power output and efficiency. Power output is measured in watts or kilowatts. Efficiency is the ratio of signal power output to total power input (wattage demanded of the power supply or battery). This value is always less than 1. It is typically expressed as a percentage. In audio applications, power amplifiers are 30 to 50 percent efficient. In wireless communications and broadcasting transmitters, efficiency ranges from about 50 to 70 percent. In hi-fi audio power amplifiers, distortion is also an important factor. This is a measure of the extent to which the output waveform is a faithful replication of the input waveform. The lower the distortion, in general, the better the fidelity of the output sound.

Amplifiers are classified into classes according to their construction and operating characteristics are shown on Fig. 6.

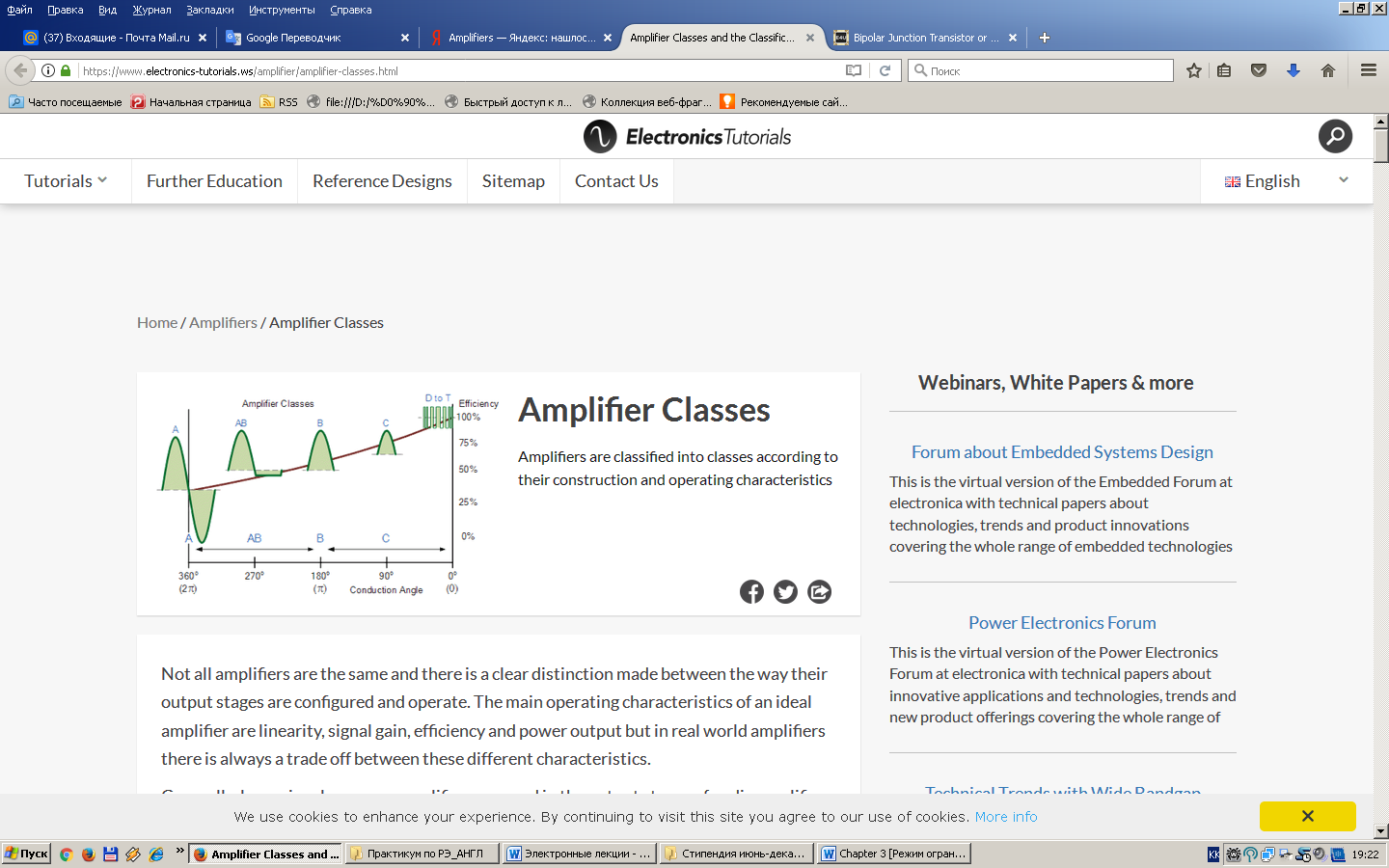


Fig. 6

Not all amplifiers are the same and there is a clear distinction made between the way their output stages are configured and operate. The main operating characteristics of an ideal amplifier are linearity, signal gain, efficiency and power output but in real world amplifiers there is always a trade off between these different characteristics.

Generally, large signal or power amplifiers are used in the output stages of audio amplifier systems to drive a loudspeaker load. A typical loudspeaker has an impedance of between 4Ω and 8Ω, thus a power amplifier must be able to supply the high peak currents required to drive the low impedance speaker.

One method used to distinguish the electrical characteristics of different types of amplifiers is by “class”, and as such amplifiers are classified according to their circuit configuration and method of operation. Then **Amplifier Classes** is the term used to differentiate between the different amplifier types.

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**Theme 5:** **Power supplies and autogenerators**

*Question:*

*1*. Amplifier Classes

*2. Rectifiers*

*3. Smoothing filters*

*4. Voltage stabilizers*

*5. Oscillators of harmonic oscillations*

Amplifier Classes represent the amount of the output signal which varies within the amplifier circuit over one cycle of operation when excited by a sinusoidal input signal. The classification of amplifiers range from entirely linear operation (for use in high-fidelity signal amplification) with very low efficiency, to entirely non-linear (where a faithful signal reproduction is not so important) operation but with a much higher efficiency, while others are a compromise between the two.

Amplifier classes are mainly lumped into two basic groups. The first are the classically controlled conduction angle amplifiers forming the more common amplifier classes of A, B, AB and C, which are defined by the length of their conduction state over some portion of the output waveform, such that the output stage transistor operation lies somewhere between being “fully-ON” and “fully-OFF”.

The second set of amplifiers are the newer so-called “switching” amplifier classes of D, E, F, G, S, T etc, which use digital circuits and pulse width modulation (PWM) to constantly switch the signal between “fully-ON” and “fully-OFF” driving the output hard into the transistors saturation and cut-off regions.

The most commonly constructed amplifier classes are those that are used as audio amplifiers, mainly class A, B, AB and C and to keep things simple, it is these types of **amplifier classes** we will look at here in more detail.

***Class A Amplifiers*** are the most common type of amplifier topology as they use just one output switching transistor (Bipolar, FET, IGBT, etc) within their amplifier design. This single output transistor is biased around the Q-point within the middle of its load line and so is never driven into its cut-off or saturation regions thus allowing it to conduct current over the full 360 degrees of the input cycle. Then the output transistor of a class-A topology never turns “OFF” which is one of its main disadvantages.

Class “A” amplifiers are considered the best class of amplifier design due mainly to their excellent linearity, high gain and low signal distortion levels when designed correctly. Although seldom used in high power amplifier applications due to thermal power supply considerations, class-A amplifiers are probably the best sounding of all the amplifier classes mentioned here and as such are used in high-fidelity audio amplifier designs.

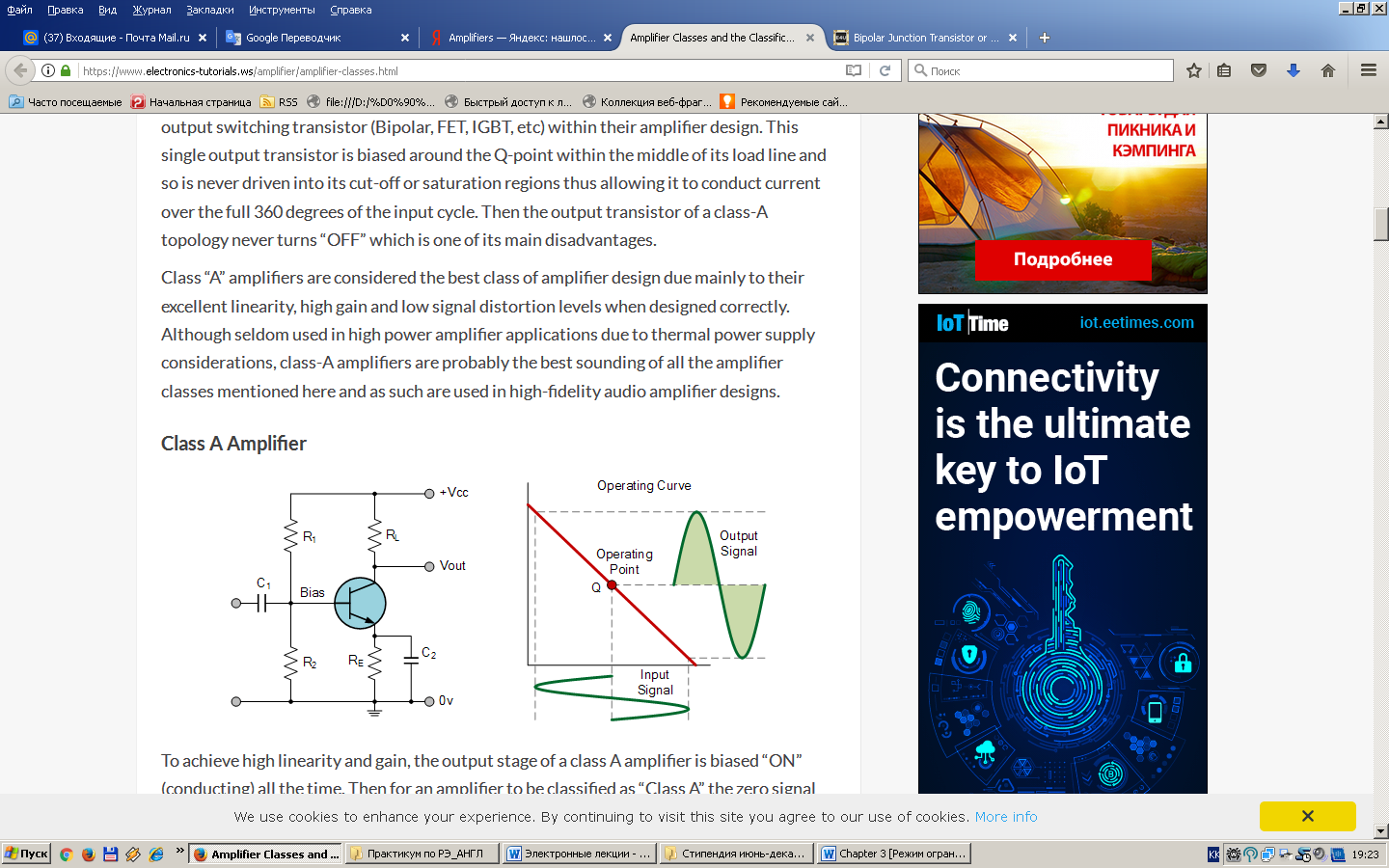


Fig. 6

To achieve high linearity and gain, the output stage of a class A amplifier is biased “ON” (conducting) all the time. Then for an amplifier to be classified as “Class A” the zero signal idle current in the output stage must be equal to or greater than the maximum load current (usually a loudspeaker) required to produce the largest output signal.

As a class A amplifier operates in the linear portion of its characteristic curves, the single output device conducts through a full 360 degrees of the output waveform. Then the class A amplifier is equivalent to a current source.

Since a class A amplifier operates in the linear region, the transistors base (or gate) DC biasing voltage should by chosen properly to ensure correct operation and low distortion. However, as the output device is “ON” at all times, it is constantly carrying current, which represents a continuous loss of power in the amplifier.

Due to this continuous loss of power class A amplifiers create tremendous amounts of heat adding to their very low efficiency at around 30%, making them impractical for high-power amplifications. Also due to the high idling current of the amplifier, the power supply must be sized accordingly and be well filtered to avoid any amplifier hum and noise. Therefore, due to the low efficiency and over heating problems of Class A amplifiers, more efficient amplifier classes have been developed.

*Class B amplifiers* were invented as a solution to the efficiency and heating problems associated with the previous class A amplifier. The basic class B amplifier uses two complimentary transistors either bipolar of FET for each half of the waveform with its output stage configured in a “push-pull” type arrangement, so that each transistor device amplifies only half of the output waveform.

In the class B amplifier, there is no DC base bias current as its quiescent current is zero, so that the dc power is small and therefore its efficiency is much higher than that of the class A amplifier. However, the price paid for the improvement in the efficiency is in the linearity of the switching device.

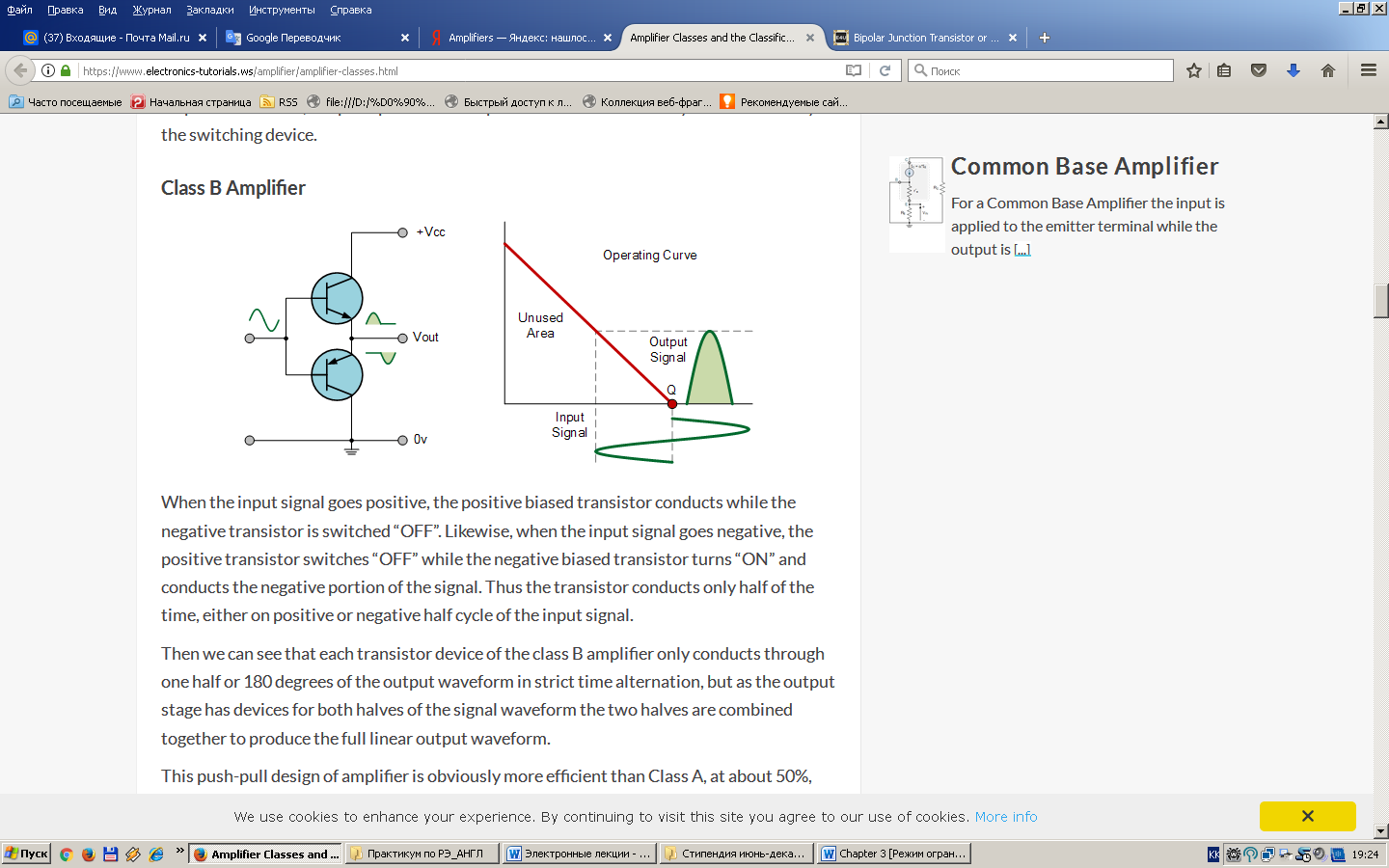


Fig. 7

When the inputsignal goes positive, the positive biased transistor conducts while the negative transistor is switched “OFF”. Likewise, when the input signal goes negative, the positive transistor switches “OFF” while the negative biased transistor turns “ON” and conducts the negative portion of the signal. Thus the transistor conducts only half of the time, either on positive or negative half cycle of the input signal.

Then we can see that each transistor device of the class B amplifier only conducts through one half or 180 degrees of the output waveform in strict time alternation, but as the output stage has devices for both halves of the signal waveform the two halves are combined together to produce the full linear output waveform.

This push-pull design of amplifier is obviously more efficient than Class A, at about 50%, but the problem with the class B amplifier design is that it can create distortion at the zero-crossing point of the waveform due to the transistors dead band of input base voltages from -0.7V to +0.7.

This means that the the part of the waveform which falls within this 0.7 volt window will not be reproduced accurately making the class B amplifier unsuitable for precision audio amplifier applications.

To overcome this zero-crossing distortion (also known as Crossover Distortion) class AB amplifiers were developed.

As its name suggests, the ***Class AB Amplifier*** is a combination of the “Class A” and the “Class B” type amplifiers we have looked at above. The AB classification of amplifier is currently one of the most common used types of audio power amplifier design. The class AB amplifier is a variation of a class B amplifier as described above, except that both devices are allowed to conduct at the same time around the waveforms crossover point eliminating the crossover distortion problems of the previous class B amplifier.

The two transistors have a very small bias voltage, typically at 5 to 10% of the quiescent current to bias the transistors just above its cut-off point. Then the conducting device, either bipolar of FET, will be “ON” for more than one half cycle, but much less than one full cycle of the input signal. Therefore, in a class AB amplifier design each of the push-pull transistors is conducting for slightly more than the half cycle of conduction in class B, but much less than the full cycle of conduction of class A.

In other words, the conduction angle of a class AB amplifier is somewhere between 180o and 360o depending upon the chosen bias point as shown (Fig. 8).

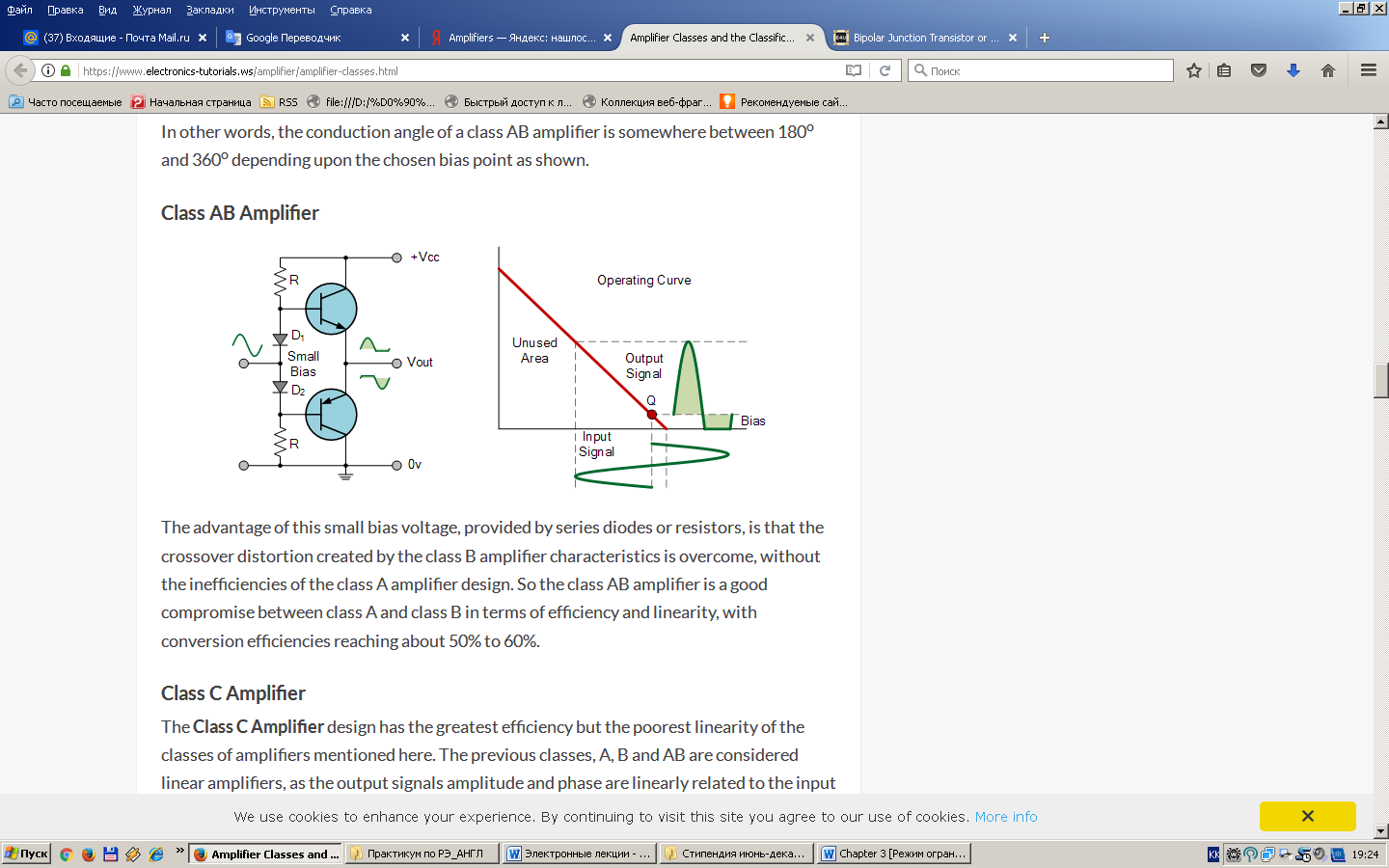


Fig. 8

The advantage of this small bias voltage, provided by series diodes or resistors, is that the crossover distortion created by the class B amplifier characteristics is overcome, without the inefficiencies of the class A amplifier design. So the class AB amplifier is a good compromise between class A and class B in terms of efficiency and linearity, with conversion efficiencies reaching about 50% to 60%.

The ***Class C Amplifier*** design has the greatest efficiency but the poorest linearity of the classes of amplifiers mentioned here. The previous classes, A, B and AB are considered linear amplifiers, as the output signals amplitude and phase are linearly related to the input signals amplitude and phase.

However, the class C amplifier is heavily biased so that the output current is zero for more than one half of an input sinusoidal signal cycle with the transistor idling at its cut-off point. In other words, the conduction angle for the transistor is significantly less than 180 degrees, and is generally around the 90 degrees area.

While this form of transistor biasing gives a much improved efficiency of around 80% to the amplifier, it introduces a very heavy distortion of the output signal. Therefore, class C amplifiers are not suitable for use as audio amplifiers (Fig. 9).

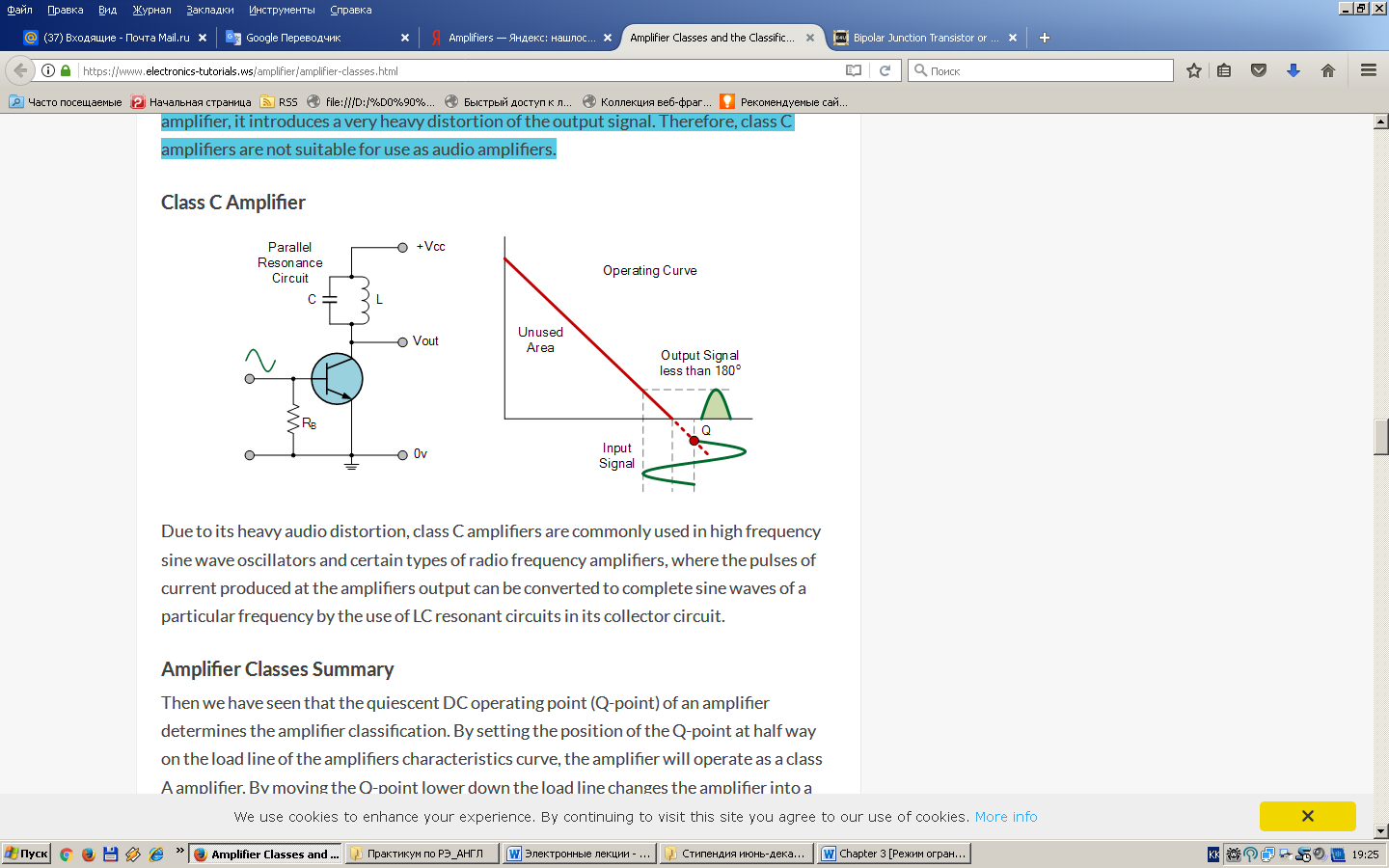


Fig. 9

Due to its heavy audio distortion, class C amplifiers are commonly used in high frequency sine wave oscillators and certain types of radio frequency amplifiers, where the pulses of current produced at the amplifiers output can be converted to complete sine waves of a particular frequency by the use of LC resonant circuits in its collector circuit.

## *Summary:* Then we have seen that the quiescent DC operating point (Q-point) of an amplifier determines the amplifier classification. By setting the position of the Q-point at half way on the load line of the amplifiers characteristics curve, the amplifier will operate as a class A amplifier. By moving the Q-point lower down the load line changes the amplifier into a class AB, B or C amplifier.

## *Other Common Amplifier Classes:*

* Class D Amplifier – A Class D audio amplifier is basically a non-linear switching amplifier or PWM amplifier. Class-D amplifiers theoretically can reach 100% efficiency, as there is no period during a cycle were the voltage and current waveforms overlap as current is drawn only through the transistor that is on.
* Class F Amplifier – Class-F amplifiers boost both efficiency and output by using harmonic resonators in the output network to shape the output waveform into a square wave. Class-F amplifiers are capable of high efficiencies of more than 90% if infinite harmonic tuning is used.
* Class G Amplifier – Class G offers enhancements to the basic class AB amplifier design. Class G uses multiple power supply rails of various voltages and automatically switches between these supply rails as the input signal changes. This constant switching reduces the average power consumption, and therefore power loss caused by wasted heat.
* Class I Amplifier – The class I amplifier has two sets of complementary output switching devices arranged in a parallel push-pull configuration with both sets of switching devices sampling the same input waveform. One device switches the positive half of the waveform, while the other switches the negative half similar to a class B amplifier. With no input signal applied, or when a signal reaches the zero crossing point, the switching devices are both turned ON and OFF simultaneously with a 50% PWM duty cycle cancelling out any high frequency signals.

To produce the positive half of the output signal, the output of the positive switching device is increased in duty cycle while the negative switching device is decreased by the same and vice versa. The two switching signal currents are said to be interleaved at the output, giving the class I amplifier the named of: “interleaved PWM amplifier” operating at switching frequencies in excess of 250kHz.

* Class S Amplifier – A class S power amplifier is a non-linear switching mode amplifier similar in operation to the class D amplifier. The class S amplifier converts analogue input signals into digital square wave pulses by a delta-sigma modulator, and amplifies them to increases the output power before finally being demodulated by a band pass filter. As the digital signal of this switching amplifier is always either fully “ON” or “OFF” (theoretically zero power dissipation), efficiencies reaching 100% are possible.
* Class T Amplifier – The class T amplifier is another type of digital switching amplifier design. Class T amplifiers are starting to become more popular these days as an audio amplifier design due to the existence of digital signal processing (DSP) chips and multi-channel surround sound amplifiers as it converts analogue signals into digital pulse width modulated (PWM) signals for amplification increasing the amplifiers efficiency. Class T amplifier designs combine both the low distortion signal levels of class AB amplifier and the power efficiency of a class D amplifier.

Questions:

1. What is the ripple frequency of the full-wave rectifier output voltage?

2. Class S Amplifier

3. Class T Amplifier

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