

DISPLAY SYSTEMS

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Types of display system

- 1) Active. Those that generate their own radiation.
- 2) Passive. Those that modulate ambient incident radiation (an example of this being a blackboard or a LCD display !)

Clearly, "active" devices require a power source sufficient to create the required brightness from the display. "Passive" devices require much lower power (therefore particularly suitable for battery operation).

Solid materials generate light through a process known as "luminescence". Various types of luminescence depend on the methods by which it is excited: eg **Photoluminescence** excitation due to absorption of photons. **Cathodoluminescence** due to bombardment by electrons. **Electroluminescence** due to the effect of and electric field. There are many other types but these are all we are interested in this course. Materials designed for their luminescent properties are called "**phosphors**". These are old terms now, but alternative terms employed are **fluorescence** radiation stop as soon as stimulus stopped, and **Phosphorescence** refers to a material that radiates for a time after the stimulus is removed.

General considerations

We need to consider from what point of view we are considering a material, Radiometry or Photometry.

Photometry - This is a measurement of radiation in terms of its ability to produce the psychological sensation of brightness.

Radiometry - This is the purely physical measure of the radiation which provides the visual stimulus.

We refer to the efficiency of the visual system is the ratio,

Photometric observation / Equivalent radiometric signal

fig 1

Figure one shows a graph of the human eye's efficiency for detecting light. At 555nm we have 1 Watt (radiative unit) which is defined as 680 Lumens (photometric unit). Now we compare the relative units of measurement,

Radiometric units
Power (flux), W

Photometric units
Luminous power, lm

Irradiance, W/m ²	Illuminance, lm/m ² (lux)
Radiant intensity, W/sr	Luminous intensity, lm/sr (Candela, cd)
Radiance, W/m ² sr	Luminance, lm/m ² sr (cd/m ²)

It is the measure of luminance which is really referred to as brightness.

Contrast and Contrast ratio

This can be defined in different ways, eg,

$$\text{contrast ratio} = (B_o - B_s) / B_s$$

Where B_o is the luminescence of the object and B_s is the luminescence of the surroundings.

The eye is capable of detecting differences corresponding to a contrast of ratio of 1.03. (but for white symbols in a black background, a ratio 5 is considered to be the minimum acceptable).

Flicker - Time variations in brightness

Observation of "flicker" depends on frequency. **Critical fusion frequency** (CFF) is the frequency of brightness variation for which no flicker is observed by the human eye (for the human eye, CFF is between 20 Hz and 50Hz, depending on brightness.).

Simple numeric displays

Such a display may have the form of a seven segment system (in the configuration of a "figure 8"). The devices associated with each segment share a common anode (or cathode) and there are separate connections to each of the corresponding cathodes (or anodes). Therefore any number with n digits can be formed by repeating this pattern n times and by addressing (7n+1) electrodes.

In order to reduce the number of connections use can be made of the coordinate (or matrix) connected method. Each common element in each digit are connected to a common input line, then we can selectively set the anode line

fig 2

All the anodes of elements in each row (or column) are connected together. Similarly, all the cathodes in each column (row). Therefore a system with (m×n) elements requires only (m+n) connections. eg, for an array of 12 digits in 7 segments format simple "direct drive"

requires the format,

$$7 \times 12 + 1 = 85 \text{ leads}$$

but matrix connection requires $7 + 12 = 19$ leads

fig 3

With matrix format, the required display pattern cannot be provided by applying fixed voltages to the leads. Timesharing (or multiplexing) is employed. The required voltage, V , is applied to a particular row and the necessary signal is applied simultaneously to each of the columns (depending on whether that particular segment should be 'on' or 'off'). After a time, t , voltage, V , is switched to the next row and a new set of signals are applied to the columns. If there are n rows, a time nt will be required to produce the full pattern. To avoid flicker it is necessary for nt to be less than about $1/40$ seconds. The observed brightness of each element will be less than would be the case under "direct drive" as it will be in the on state for only $1/n$ of the total 'on' time. Therefore it is necessary for the display to be "overdriven" in order to increase its time average brightness.

Under matrix connection each element when in the 'off' state. Ideally there should be no output from such elements. The ideal characteristic for matrix address display devices is shown in figure 4.

fig 4

Devices should have;

- fast rise time
- high brightness

Alternatively, use of "memory" mode operation can be made.

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Cathode Ray Tube (CRT) display systems

(See sheet)

High voltages are required for both the beam acceleration and deflective processes.

Structure of phosphor screen: The phosphor is a highly insulating material, there is a large band gap between the valence and conduction band. As it is bombarded with electrons, it knocks the phosphor's electrons into the conduction band from the valence band, thus creating an electron-hole pair. It is recombination of these that gives us photon emission. Dopants in the phosphor are used to allow various colours to be

displayed. A phosphor screen is made up of phosphor grains approximately 5 μm in diameter.

fig 1

Cathodoluminescence process

High energy electrons lose energy in phosphor by ionisation, with production of electron-hole pairs. The depth of penetration of electrons with an increase in the electron beam energy (At 10 KeV, depth is $\sim 1\mu\text{m}$ in 2ns). The Luminescence efficiency with beam energy. (At low beam energy electron-hole pairs are created near the surface of phosphor where there are many non-radiative centres).

Rastering

The screen is divided into 625 lines (as per the European standard). To avoid flicker, the full screen must be scanned at a rate equal to or greater than 40 Hz (the fusion frequency). This requirement is eased in practice by use of "double scanning": Lines 1,3,5,7 and so on are scanned in a time which half of the time to scan the whole screen. The lines 2,4,6,8 and so on are scanned at half the period. The eye responds as if repeat rate is $2/t$ Hz instead of $1/t$ Hz. Therefore, a repeat time of $1/25$ s can be used (this is the European standard).

Variation in brightness is determined by beam current. The phosphor must have a decay time less than t to avoid "streaking" (due to image persistence, and where t is the period of full screen scan).

Colour Methods

1) Shadow mask (see sheet).

Flat CRT

A type of flat CRT proposed was the **Aiken system**

fig 2

Another flat CRT was the **Gabor system**,

fig 3

Line scan is provided deflection plates in the usual way. 180 degree

beam reversal provides improved utilisation of flat plate area.

Both designs requires large numbers of plates to be switched at high voltages (+ high rate).

If used in conjunction with a channel multiplier plate, the switching can be performed at low voltages (the whole system need be only few cm deep).

Frame plates provided with a ramp voltage which steps from plate to plate in sequence. As each strip is raised to 400V the beam moves further to the right before being deflected.

fig 4

PLASMA DISPLAY SYSTEMS

The gas discharge process:

Consider the current flowing between two electrodes, in a at low pressure.

fig 5

As the electric field is increased, any charged particles gain sufficient energy to ionize gas atoms or molecules. Ions striking the cathode cause liberation of electrons - these are accelerated and cause further ionization. The mixture of ions and electrons are known as plasma. Radiation from plasma is due to electron transitions between excited states and lower energy states of gas atoms. Characteristic of the gas atom involved determines the wavelengths of the emission, ie the colour (Neon is a commonly employed gas).

In a vacuum we would expect the voltage to vary linearly across the container. However, if the container is full of a plasma, the voltage increases quickly (and hence most excitations occur) at the cathode and reaches a high value, the voltage does not increase as much as we pass the middle and towards the anode. This is known as the **cathode glow**.

Plasma Display Panels (PDP)

Structure and operation of DC systems. Electron systems deposited onto glass. The cathode defines areas of illumination. (see sheet). Such devices have a thick metallic film (eg Nickel, it has a low work function). Anodes may be a conducting/transparent layer (eg ITO, Indium Tin Oxide). Two glass plates sealed together with spacer keeping electrodes approximately 0.5 mm apart. The space between the electrodes is normally evacuated and then filled with gas at low

pressure (100-300 Torr).

Main problems with simple this structure;

- Discharge does not occur immediately on application of address voltage.
- Random variations in firing time causes variations in brightness.

Structure and operation of AC systems. Electrode construction on glass plates as for DC panels but also material used for cathode not so important. Electrode systems subsequently are coated with an insulating material (eg SiO₂) plus further protective layer of MgO. Plates are sealed together with a spacer (~0.1mm), the gas pressure is 300-600 Torr. Operation involves a "memory" function.

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They lay out of such a system is shown in fig 1.

fig 1

However in practice the construction is like in fig 2.

fig 2

The overall cell voltage is contributed to by several sources. There is the supply voltage called the **sustaining voltage** and then there is what is called the **wall voltage** due to the *wall charge*. The wall charge comes about because as the external field applied to the cell causes a build up of charge on the side of the insulator we get an internal field due to the *wall charge*. Hence,

$$V_c = V_s + V_w$$

If $V_c > V_a$ then the discharge occurs but build-up of the wall charge rapidly causes extinction of it. V_a is the discharge voltage. The sustaining voltage is never larger than the discharge voltage, hence an extra pulse is required to initiate the process. The extra pulse comes by means of the sum of the sustaining voltage and the wall voltage (see sheet).

The *memory* function is simply that once a cell has been started it keeps going. So seemingly *remembering* it was activated. An opposite pulse has to be used to stop the process running, this would remove the charge build up on the insulators.

Vacuum Fluorescent Displays (VFD's)

These are devices which operate using cathode rays. It was found (in the 1960's in Japan) that certain materials would fluoresce with lower energy cathode rays.

ZnO:Zn	G/B	5-7 L/W
ZnS:Mn	Yel.	0.5 L/W
ZnCl:Ag	Red	0.5 L/W

fig 3
fig 4

Electroluminescent Displays (EL)

EL luminescence arising from the application of an electric field. This has been observed in single crystals and in polycrystalline thin films placed between suitable electrodes under alternating current conditions. Also observed in carbon P-N junctions under forward or reverse bias.

EL in the above cases cannot be explained in terms of a single mechanism. Different types of excitation process are responsible for the excitation in the structures referred to above.

Excitation Process:

1) Quantum Mechanical tunneling

fig 5
fig 6

Figure 5 shows the energy routes for excitations of electrons. Figure six shows the effect of applying a potential difference across the region. As is shown there are non-horizontal energy lines, so electrons can gain kinetic energy. For a high potential gradient, it is possible for electrons to tunnel through from the Fermi energy level to the conduction band, see fig 7.

fig 7

The photon emission, obviously occurs as an excited electron transits from the conduction band to the valence band and recombines with a

hole.

2) Avalanching (impact ionization)

fig 8

The electron reaches an energy sufficient to excite an electron from the valence band

fig 9

The hole becomes trapped

fig 10

The conduction band electron makes a radiative transition.

3) Minority carrier injection

fig 11

figure 11 shows an unbiased PN junction.

Now, figure 12 shows a **forward biased** junction. Injected minority carriers recombine with majority carriers.

fig 12

It is the recombination of the minority carriers that we depend on for photon emission.

Device Structures

Electroluminescence was first discovered in 1936 using ZnS phosphor (powder) held in an insulating "binder" clamped between two parallel plates.

fig 13

Under AC (~ several hundred volts) light is emitted in pulses (1 for each $\frac{1}{2}$ cycle).

MISIM structure(Metal Insulator Semiconductor, ...)

fig 14

Features:

- i) Very good power conversion efficiency.
- ii) Good prospects for developments in large area displays (currently in use in some portable computers).

Mechanisms:

- i) Electrons produced at I-S interface (by tunnel injection).
- ii) These electrons are accelerated by the electric field ($\sim 10^6$ V/cm) in the phosphor. This effect is multiplied by impact ionization.
- iii) Mn centres are also excited by electric impact.
- iv) Mn centres emit (yellow) light.

Multicolour Displays

- 1) Different colours can be obtained by using different impurities (e.g. rare earths: Sm for red, Tb for green and Tb for blue but luminescent efficiencies are not as high as for Mn doped ZnS).
- 2) Recently, interest has been shown in other EL materials (eg CaS, SrS).

Phosphor	Typical	Characteristic Colour	
	Emiss. at 1Khz. Cd/m ²	Effic. lm/W	
CaS, Eu	170	.05	Red
CaS, Ce	800	.2	Green
SrS, Ce	680	.3	Blue/Green
ZnS, Sm	200	.08	Red/orange
ZnS, Tb	1000	1.5	Green
ZnS, Tm	10	.01	Blue
2000	2000	1-5	Yellow

30/04/1999Light Emitting Diodes (LED's)**fig 1**

Figure 1 shows a schematic of a typical LED. Under forward bias, the current density crossing the junction is given by,

$$I = ((eD_p p_n / L_p) + (eD_n n_p / L_n)) (\exp(eV/kT) - 1)$$

(Where D is the diffusion coefficient, L is the coefficient of dopant concentration fall-off. p_n and n_p are minority carrier concentration) Light generated on the side of the junction closest to the surface has a greater chance of being emitted rather than re-absorbed. Most of the current crossing the junction should be due to electron injection into the p-type material (for the case shown in figure one). The fraction of the total current due to electron injection is,

$$\begin{aligned} I_e / I_o &= (D_n n_p / L_n) / ((eD_p p_n / L_p) + (eD_n n_p / L_n)) \\ &= (1 + (D_p p_n L_n / D_n n_p L_p))^{-1} \end{aligned}$$

For many materials used in LEDs, $D_n \gg D_p$ and it can be arranged that $p_n \ll n_p$, by making the n-type material more heavily doped than the p side (ie n⁺-p diode). Therefore, $I_e \approx I_o$.

Probability of emitted radiation escaping from a device

The problem lies with total internal reflection.

fig 2

Light originating at recombination centres near to the p-n junction will be radiated isotropically but only a fraction of this can penetrate the surface.

According to Snell's law $n_1 \sin(\theta_1) = n_2 \sin(\theta_2)$ when n_1 and n_2 are the refractive indices in materials 1 and 2 ($n_2 < n_1$).

The critical angle occurs when $\theta_2 = 90$ degrees. ie,

$$\begin{aligned} n_1 \sin(\theta_c) &= n_2 \\ \text{or} \\ \theta_c &= \sin^{-1}(n_2 / n_1) \end{aligned}$$

Therefore the light within a cone with a planar angle of $> \theta_c$ is transmitted.

Fraction of radiation emitted from a device

The only light emitted will be that within the cone which has a planar angle of $> \theta_c$.

Therefore, the fraction, F, is given by area of sphere (radius r) cut by the cone divided by the total area of the sphere.

fig 3

Figure demonstrates how we use geometry to break down and

calculate F.

Consider the circular strip of radius $r \cdot \sin(\theta)$. The width of this strip is $r \cdot d\theta$. Therefore, the area of the strip is,

$$2\pi r \sin(\theta) \cdot r d\theta \\ = 2\pi r^2 \sin(\theta) d\theta$$

Therefore the area cut by the cone of angle $2\theta_c$ is,

$$\text{Integ}(\theta_0) \{2\pi r^2 \sin(\theta) d\theta\} \\ = 2\pi r^2 (1 - \cos(\theta_c))$$

Therefore,

$$F = \frac{2\pi r^2 (1 - \cos(\theta_c))}{4\pi r^2} \\ = \frac{1}{2} [1 - \cos(\theta_c)]$$

It has been shown that $\theta_c = \sin^{-1}(n_2/n_1)$. For LED material with $n=3.4$ in air,

$$\sin(\theta_c) = 1/3.4$$

so that $\theta_c \approx 17$ degrees. Therefore light escaping fraction F is,

$$F = \frac{1}{2} (1 - 0.96) = 0.02$$

Methods for increasing the emission fraction:

- 1) Shaping the semiconductor-air interface so that more light will strike the the surface at less than the critical angle.
- 2) Encapsulating the device in a transparent medium with a high refractive index (and suitably shaped surface).

Semiconductor materials used for constructing diodes

Emitted light - wavelength requirement.

For transitions between the bottom of the CB and the top of the VB, energy of emitted photon is,

$$h\nu = hc/\lambda = E_c - E_v = E_g$$

$$\text{ie, } \lambda = hc/E_g$$

For transitions involving energy levels in the band gap,

$$\lambda > hc/E_g$$

for visible radiation, we require λ in the range 400-700 nm (ie 3.1 eV to 1.8 eV).

fig 4

We have to consider another factor now, the effect of the nature of the band gap, the band gap can be either direct or indirect. The need for conservation of momentum (as well as energy) has an effect on recombination transitions.

For direct band gaps, then conduction band minimum and valence band maximum (on an E-K plot, see semiconductors) lies along the same k value, this means corresponding carriers have the same momentum.

For indirect band gaps the conduction band minimum and valence band maximum lie at different k value, ie different momentum states for corresponding charge carriers.

Radiative recombination

We wish now to determine whether the above factors affect the recombination process.

1) Interband transitions

We have to require conservation of energy and momentum. For indirect band gaps, interband transitions means that the momentum of a charge carrier has to change. Momentum is expressed as shown below,

$$\begin{aligned} \text{momentum} &= p = k \cdot h / 2\pi = k \cdot \hbar \\ k &= 2\pi / \lambda \end{aligned}$$

The wave vector (k) for an emitted photon in the visible spectrum is,

$$2\pi / \lambda = 2\pi / 500 \text{ nm}$$

The wave vectors for the electrons involved are in the range, $-\pi/a$ to $+\pi/a$ where a is the crystal lattice spacing ($a \approx 0.35 \text{ nm}$).

As $2\pi / \lambda \ll \pi/a$ a transition involving only an electron and a photon will appear as a nearly vertical transition on an E-K diagram (ie a **direct transition**)

Non-vertical transitions are possible but these must involve phonons in order to conserve momentum, or k . Phonon energy is very small so that photon energy is still close to the band gap energy, E_g .

But with three particles involved instead of two, such indirect transitions are less probable.

2) Impurity centre transitions.

When an electron is trapped (localised) it can be seen to have a range of momentum values. The Heisenburg uncertainty principal states,

$$\begin{aligned} \mathbf{dx.dp} & \Rightarrow \hbar/2 \\ \text{Since, } \hbar \mathbf{dkdp} & \\ \mathbf{dk} & \Rightarrow 1/2\mathbf{dx} \end{aligned}$$

Where dx is the atomic spacing.

It has been found that as we increasingly dope GaAs with more and more GaP, that is goes from being a direct band gap material to an indirect band gap materials.

fig 5

For $\text{GaAs}_{1-y}\text{P}_y$ with $y < 0.48$, there is a direct band gap and the quantum efficiency for radiative transitions is high. (Quantum efficiency is number of photons generated per electron/hole pair).

For $y > 0.48$, the material has an indirect band gap and the radiative efficiency is reduced because the lattice interactions must participate in the process to conserve momentum.

For indirect band gap materials, additional recombination centres are incorporated to increase the probability of radiative transitions.

In GaAsP, incorporation of nitrogen is successful (Nitrogen is from the same group as for P. If substitutions for P but the different electronic core structure remains in the formation of an electron "trap" just below the conduction band - an interelectronic centre).

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Factors influencing wavelength distribution of emitted photons

- 1) Band gap energy, E_g
There is a corresponding wavelength, $\lambda_g = hc/E_g$. (we need to consider the effect of temperature and the distribution of electrons in bands.)
- 2) Effect of self-absorption before the photon can escape.
- 3) Emission involving energy levels within the bandgap.

Factors influencing the internal quantum efficiency

(Quantum efficiency = number of photons generated per electron/hole pair)

- 1) Band to band recombination probability (dependant on use of "direct" and "indirect" bandgap materials).
- 2) Existence of non-radiative recombination paths (require high purity, high quality materials).

Liquid Crystal Displays (LCD.)

LCDs are passive systems, they operate on the the principal of modulation of ambient light in reflection of transmission modes.

LCD cells consist of a layer of liquid crystals (~ 10µm thick) between two glass plates coated with conductive, transparent layers.

Liquid Crystal materials

The liquid crystal state is a phase of matter exhibited by a wide range of organic substances. These are composed of molecules which str highly non-spherical (e.g. rod shape).

The molecules can take up particular orientations relative to each other and relative to surfaces with which they are in contact (ie. they become ordered). This ordered phase only exists over a particular temperature range. At lower temperatures the material is solid at higher temperature the normal liquid phase exists. There are three broadly different types of liquid crystals: Nematic , Cholerteric , Smetic.

The Nematic phase is the most widely used for device purposes. Nematic molecules tend to lay parallel to each other but random along each other, there are two types. The **homeotropic** type lie perpendicular to the surface of the material, **homogeneous** lie parallel to the surface of the material.

Smetic molecules lie parallel to each other too, but they are also layered too in thier order. There also the homeotropic and homogeneous varieties too.

Cholerteric molecule show similar layered orientations as Smetic, but each layer is not aligned to other layers. The alignment of the molecules is twisted through space, there is a characteristic depth for a complete twist to occur. A complete twist always takes the same number of

molecule layers. This characteristic is called the "characteristic pitch".

fig 1

Liquid crystals are anisotropic. eg, a dielectric constant can be defined for parallel and perpendicular directions relative to the molecular axis.

If $dE = E_{\text{par}} - E_{\text{per}}$ is positive an electric field will cause molecules to align parallel to the field direction. Similarly, if dE is negative to molecules will align perpendicular to an electric field. Typically dE values range from -0.4 to +10.

Example:

Consider nematic phase in homogeneous form with E-Field applied perpendicular to surface (assuming dE is positive)

fig 2

E_c is the critical E-field for which the majority of molecules are aligned parallel to the field direction.

The "Twisted Nematic" cell

(See sheet)

Structure: A nematic material (dE positive) contained between two surfaces treated to produce the homogeneous state but the alignment directions on the two surfaces are mutually perpendicular so that molecular alignment undergoes a 90 degree rotation between the plates.

fig 3

Effect on light: When polarised light is incident, the strong optical anisotropy causes polarization to undergo a 90 degree rotation (for $E < E_c$) (see bottom of sheet again).

LCD Structure

Figure 4 shows a cross section for a twisted cell,

fig 4

(located on back of sheet!)

Molecular alignment layers:

needed to ensure a stable and uniform molecular orientation in

the LC in absence of applied field.

Techniques:

- (1) Rubbing
- (2) Coating with solution
- (3) Aligning again in LC
- (4) Oblique evaporation

Required LC characteristics:

- 1) Wide working temperature range for liquid crystal phase.
- 2) Good chemical + photochemical stability (long life)
- 3) Low viscosity (fast speed of response)
- 4) Large dielectric anisotropy (low voltage operation)
- 5) Good voltage discrimination (for matrix applications).

Operational characteristics necessary for devices to be used in MATRIX DISPLAY systems.

- 1) Require good brightness-voltage discrimination

fig 5
(see back of sheet again!)

2) To avoid "flicker", signal repeat rate \Rightarrow 30 Hz with n display lines, device "on" for only $1/n$ of scan time, T . Therefore we must have fast response time ($< T/n$).

3) Require high brightness, as time-averaged brightness is much less than steady state.

Clearly factors (ii) and (iii) limit the number of display elements which can be included in the system.

The "Guest Host" cell (GH)

A dichroic dye (the guest) is mixed with the liquid crystal (the host). The dye molecules tend to align with the liquid crystal molecules so that their alignment can be changed by an applied field. As the light absorption of the dye is dependant on orientation, colour changes can be produced. Different types of GH cell are possible depending on types of LC and types of dye.

eg, GH cell using nematic LC with homogeneous orientation.

fig 6

(back of sheet again!)

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Active Matrix Arrays

fig 1

To address a particular element, the transistor gate is "opened" by applying suitable voltage to appropriate y line the voltage on the corresponding x line then appears across the device (common connection to all elements is not shown in fig 1). As the LCD consumes very little current, the element will remain *on* for some time after the FET is switched off.

Each pixel circuit can be represented by a combination of capacitance **C** (due to the LC device element (LCD!)) and a resistance **R** associated with the FET) in series. The array is addressed by applying a voltage pulse sequentially to each gate line (which reduces the effective resistance of the FET). The required charge must be transferred to the LCD during this pulse (while the transistor is *on*). Subsequently, this charge is required to remain on the LCD pixel (without loss) for the remainder of the frame time.

Required properties of FETs

Consider a display consisting of 100 lines. Let full frame time is $T=20\text{ms}$. Therefore, t , address time for each line $=20\text{e-}3/100=0.2\text{ms}$. If FET resistance when *on* is R_{on} , the time constant for the circuit is then $R_{\text{on}}C$. For C to be fully charged, it is required that,

$$R_{\text{on}}C \ll t$$

Say $t \sim 5R_{\text{on}}C$. Typically $C \sim 1\text{pF}$, therefore $R_{\text{on}} < 0.2\text{e-}3/5\text{e-}12 = 4\text{e}7$ Ohms.

For negligible loss of charge during the *off* period.

$$R_{\text{off}}C \gg T \text{ (say } 100.T)$$

Therefore,

$$R_{\text{off}} \sim 20\text{e-}3 * 100 / 10\text{e-}12$$

The End, bye bye :*)