# Microwave Theory and Techniques

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## Module - 7
## Lecture – 31
## Microwave Transistors: BJT, HBT, JFET, MOSFET, MESFET and HEMT

Hi. In this lecture, we will talk about Microwave Transistor. So, let us start the lecture. So, transistor is a basic building block in electronic devices. It has replaced many of the vacuum tubes in electronic circuits. The output current or power or voltage of a transistor is controlled by either the input current or the input voltage of the transistor. Now, depending upon that the transistors, they are divided into 2 categories; Bipolar Junction Transistor and Field Effect Transistor. In case of Bipolar Junction Transistor, the output current of the transistor is controlled by the input current of the transistor.

In these transistors, the current conduction is due to 2 type of charge carriers; electrons and holes. Now, depending upon the type of charge carriers, they are divided into 2 categories; PNP and NPN type.

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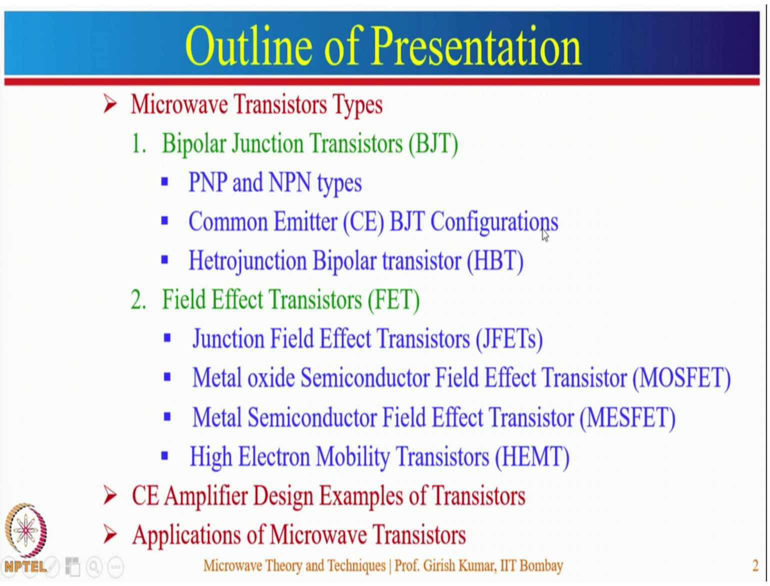

Outline of Presentation

- Microwave Transistors Types
  1. Bipolar Junction Transistors (BJT)
     - PNP and NPN types
     - Common Emitter (CE) BJT Configurations
     - Hetrojunction Bipolar transistor (HBT)
  2. Field Effect Transistors (FET)
     - Junction Field Effect Transistors (JFETs)
     - Metal oxide Semiconductor Field Effect Transistor (MOSFET)
     - Metal Semiconductor Field Effect Transistor (MESFET)
     - High Electron Mobility Transistors (HEMT)
- CE Amplifier Design Examples of Transistors
- Applications of Microwave Transistors

In case of PNP transistors, holes are the majority carriers and electrons are the minority carriers. However, in case of NPN transistors, electrons are the majority carriers and holes are the minority carriers. Now, the most commonly used configuration of the transistor is a Common Emitter Bipolar Junction Transistor Configuration. Now, these transistors do not provide desirable characteristics at higher frequencies due to their high bass resistance and it limits the transition frequency of the transistor.

So, there is a new type of Bipolar Junction Transistor that is known as Heterojunction Bipolar Transistor. It utilizes the different semiconductor material to form emitter and base junction and provides low base resistance. So, they can operate up to very high frequency range. Next type of transistor is Field Effect Transistor. It is a unipolar device; it means that the current conduction in these transistors is due to only one type of charge carriers, it could be either electron or hole. The output current in this transistors is controlled by the input voltage of the transistor.

Now, these transistors are further subdivided into various categories depending upon how the channel is isolated with the gate. In case of Junction Field Effect Transistors, the gate is isolated from the channel using a reverse bias PN junction. In case of Metal Oxide Semiconductor Field Effect Transistors, the gate is isolated from the channel using an insulating oxide layer. So, that is why they are known as Metal Oxide Semiconductor.

The next type of semiconductor is Metal Semiconductor Field Effect Transistor. In this, the gate is on the top of the semiconductor transistor. So, in this case the reverse bias PN junction is replaced by the metal semiconductor short key region and that is why they are known as Metal Semiconductor Field Effect Transistor. The next type of transistor, we will talk about is High Electron Mobility Transistor. Now, all these transistors do not provide a desirable characteristic at higher frequency is due to their internal capacitance.

So, the High Electron Mobility Transistors are made, they are the hetero structures and they can operate up to very high frequencies, they provide better performance over these transistors. Then, after discussing these transistors, we will take an example of Common Emitter Amplifier Design and we will see how the various parameters affect the performance of the amplifier. Then, we will talk about the Application of Microwave Transistors.

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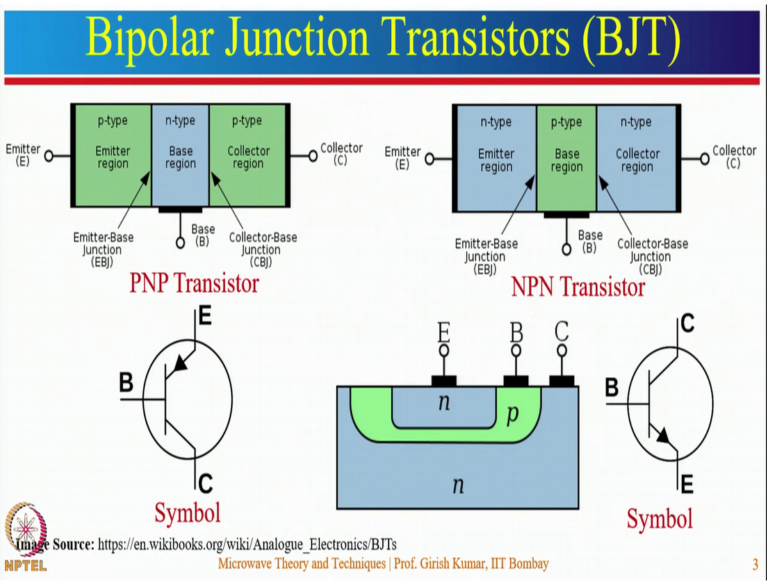

# Bipolar Junction Transistors (BJT)

PNP Transistor

NPN Transistor

Symbol

Symbol

Image Source: https://en.wikibooks.org/wiki/Analogue_Electronics/BJTs

So, a Bipolar Junction Transistor is a 3 terminal device. It is of 2 type; PNP type and NPN type. In case of PNP transistors, n type of layer is sandwich between 2 p type of layers. However, in case of NPN transistor, a p type layer is sandwich 2 n type of layer. Now these transistors are divided into 3 regions; Emitter, Base and the Collector. The Emitter is an outer mist region situated on one side of the transistor. The function of the emitter is to inject charge carriers into the collector. So, as the emitter has to inject careers, they should be highly doped.

The next type of region is the Base region. The function of the base region is to pass these charge carriers into the collector. So, this should be lightly doped and they are relative very thin and the function of the Collector region is to collect the charge carriers. So, they should have relatively more space, they are situated on other side of the transistor as shown in this geometry. Now, if this transistors is to be used in circuit, they are represented by these symbols. Here, the arrow represents the direction of current flow.

So, in general the current flows from the p type region to the n type region. So, in case of PNP transistors, current flows from emitter to the base; however, in case of NPN transistor current flows from base to the emitter. Now, these regions form 2 types of junctions; one junction is formed between Emitter and Base region and another junction is formed between Collector and Base region. This junction is called as the Emitter-Base Junction and this junction is called as the Collector-Base Junction.

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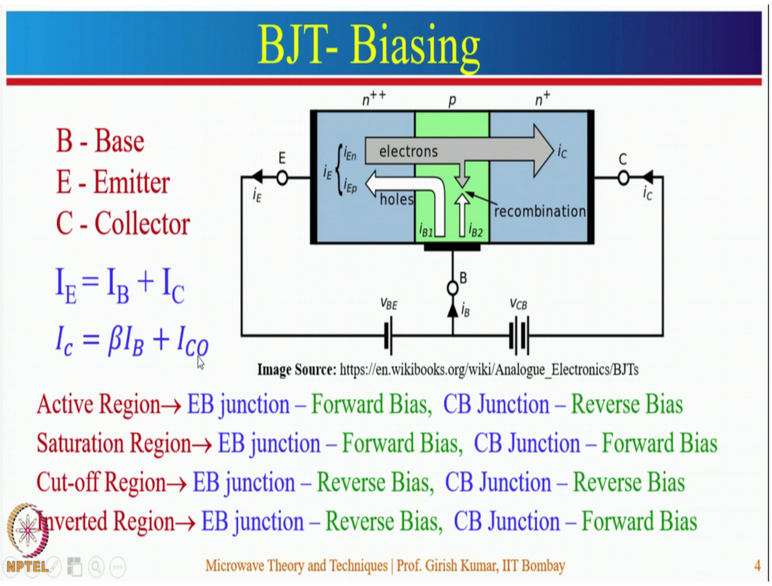

BJT- Biasing

B - Base
E - Emitter
C - Collector

$I_E = I_B + I_C$

$I_c = \beta I_B + I_{CO}$

**Image Source:** https://en.wikibooks.org/wiki/Analogue_Electronics/BJTs

Active Region→ EB junction – Forward Bias, CB Junction – Reverse Bias

Saturation Region→ EB junction – Forward Bias, CB Junction – Forward Bias

Cut-off Region→ EB junction – Reverse Bias, CB Junction – Reverse Bias

Inverted Region→ EB junction – Reverse Bias, CB Junction – Forward Bias

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Now, if this transistor is biased using DC, then this is known as the Biasing of the transistor. Since, we know that there are 2 type of junctions emitter base junction and collector base junction. Now, if these junctions are biased, they can be biased either in forward bias or in reverse bias. Now, depending upon that they can be biased into 4 regions; they are known as Active Region, Saturation Region, Cut-off Region and Inverted Region. In Active Region, emitter base junction is forward bias and the collector base junction is reverse bias. In this region, the output current depends upon the input current and it is controlled by the input current. In this region the transistor is used as an amplifier.

The next region is the Saturation Region. In this region emitter base junction is forward bias and collective base junction is also forward bias. So, in this region, output current becomes independent of the input current. In this region transistor is used as a closed switch. The next region is the Cut-off Region. In this region, emitter base junction and collector base junction both are reverse bias. Since, the emitter base junction is reverse bias it does not inject careers. So, there is no current. So, in this region this transistor acts like a open switch.

The next region is the Inverted Region. In this region, emitter base junction is reverse bias and collector base junction is forward bias. So, it does not inject any charge carriers. In this region also current is 0, but this reason is not of any use to the designers. Now to understand the working principle of transistor, let us connect this transistor in active region; that means, the emitter based junction should be forward biased and the character based junction should be reverse biased.

When the emitter base junction is forward bias emitter injects the electrons into the base, this constitutes the emitter current. A few holes will also pass from the base to the emitter. Since, the majority carriers are electrons; there will be only few percent maybe around 0.5 percent current will be due to the holes passing from base to emitter. When this electron reaches to the base region, they will try to combine with the holes of the base region. Since, base is relatively thin only few electron will combine with the holes and that will constitute the base current; rest of the electron will pass to the collector. Now, these electrons will be collected by the collector and this will constitute the collector current. There will be one more component of collector current which will be due to the holes passing from collector to the base. This is known as the reverse saturation current.

So, in this case, the emitter current is the summation of the base current and the collector current. Now, if you see here the transistor is a 3 terminal device. Now if you make 1 terminal is grounded or you make it as common; then this can be realize as a 2 terminal device or a 2 port device. So, depending upon the type that which type of terminal is made common or grounded, they are divided into 3 configurations. If the base terminal is made common, then this is called as Common Base configuration. In that case, the collector current will be the output current and input current will be the emitter current. In case of emitter terminal when it is grounded or made common, then input will be given to base and the output will be measured at collector terminal this is called as Common Emitter configuration.

And the third type of configuration will be where the common collector will be made and the input will be given to the base and the output will be measured at the emitter terminal. So, this is known as the common collector configuration. Now, among these configuration, common emitter configuration is the most widely used configuration due to its desirable characteristics like it provides highest voltage gain and highest power gain.

Now, the collective current in case of emitter configuration is given by this expression. I C is equals to beta I B plus I C O; where I CO is the reverse saturation current. Here, if you see this beta I B and I CO, they are temperature dependent. So, they vary when you increase the temperature. So, there are chances that it may increase the collector current and they could be a case that because of the increase in collector current the transistor may breakdown. So, there is a need of stabilization.

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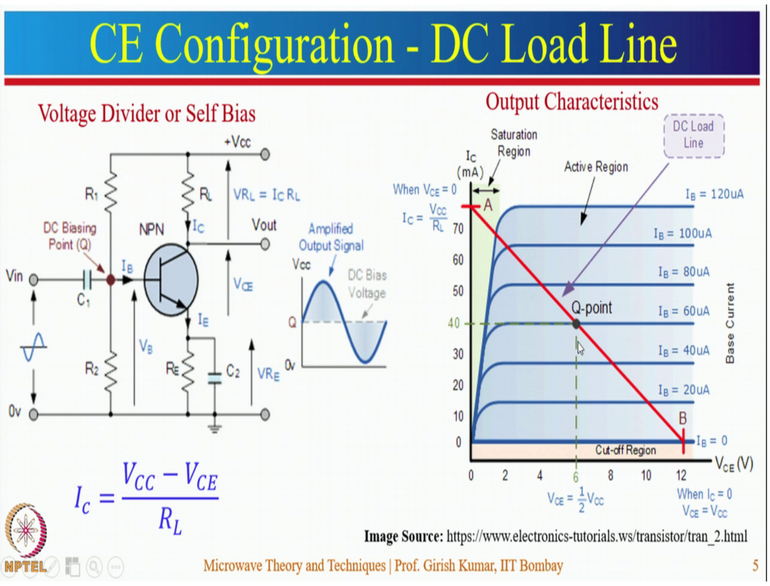

## CE Configuration - DC Load Line

Voltage Divider or Self Bias

Output Characteristics

$$I_c = \frac{V_{CC} - V_{CE}}{R_L}$$

**Image Source:** https://www.electronics-tutorials.ws/transistor/tran_2.html

So, that is why various stabilization circuits have been suggested. You can look into the literature for this. Among the biasing circuits the voltage divider biasing circuit is the most common biasing circuit. So, here is the circuit corresponding to voltage divider bias circuit. This configuration makes the I C independent of the parameter which varies with the temperature. So, in that case if the reverse saturation current increases with increase in temperature, there will be a document in base current. So, the I C will be constant.

In this case if you see I C will be given by V CC minus V CE upon R L. So, it will be constant. Now if you try to draw the output characteristics of this particular configuration that is the variation of I C with respect to V CE for the constant base current, then you will see the characteristic curves like this. Here, this reason represents the cutoff region and this region represents the saturation region. Now, if you are select a point in such a way that V CE is equals to 0; if you put the V CE value equals to 0 over here, you will get the I C is equals to V CC upon R L. This will be the maximum collector current allowable in the transistor.

Now, if you choose the another point by making the I C equals to 0; if you put I C equals 0, you will get V CE equals to VCC. So, that is represented here. Now, if you try to draw a line using these points, you will get a line like this and this line is known as the DC load line. This line decides which point; one should choose to operate in the amplifier region or in active region. Now, if you see one can choose any point corresponding to various IB’s in this particular region, but there are few drawbacks like if you select the operating point over here, there are chances that the output signal upper cycle may get clipped.

Similarly, if you select the second point somewhere here and if you try to draw the amplified output signal, there are chances that the lower cycle of this output signal may get clipped. So, this will be distorted. So, one should choose a point in such a way that the amplified output signal should not be destroyed it. So, it is suggested that you should select the centre point of DC load line to ensure the maximum output signal without distortion. So, the centre point for this DC load line will be V CC by 2 R L and 1 by 2 V CC. So, this is how one should choose the operating point.

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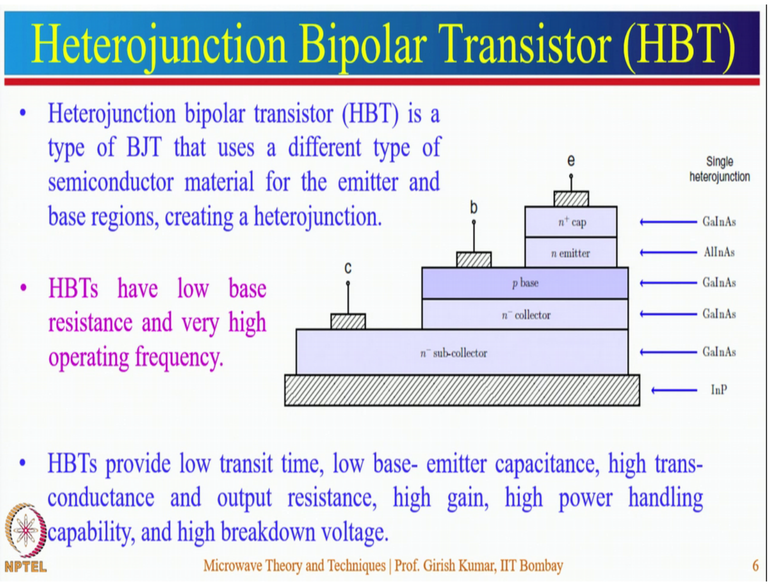

## Heterojunction Bipolar Transistor (HBT)

- Heterojunction bipolar transistor (HBT) is a type of BJT that uses a different type of semiconductor material for the emitter and base regions, creating a heterojunction.
- HBTs have low base resistance and very high operating frequency.

- HBTs provide low transit time, low base- emitter capacitance, high trans-conductance and output resistance, high gain, high power handling capability, and high breakdown voltage.

Now, as I mentioned these transistors do not work properly at higher frequencies due to their internal limitations like these transistors provide higher base resistance at the higher frequency. So, the transition frequency of these transistors will be relatively less. Now, what is transition frequency? So, transition frequency denotes the frequency and which the gain of the transistor drops down to 1. Now, why should decrease the base resistance to increase the transition frequency? So, there are configuration which was suggested this is known as the Heterojunction Bipolar Junction Transistor. In this transistor, the emitter and base region are doped by different semiconductor materials and by using heavily doped base region, the base resistance of these transistors can be reduced. So, they can operate up to very high frequency range.

So, here you can see that the emitter and base regions are made using different type of materials. Now these transistors provide better performance over other bipolar junction transistors, they provide low transition time due to the type of material used in these transistors that are like gallium arsenide and they relatively have high mobility. Similarly, they provide low bass to emitter capacitance to the lower doping of the emitter region. Similarly, they provide high trans conductance and output resistance, they also provide higher gain and they have high power handling capability and the breakdown voltages also high for these type of transistors.

So, there is a progress in these type of Heterojunction Bipolar Junction Transistors due to the development of various type of semiconductor materials and due to the improvement in the manufacturing process. Recently, hetrojunction transistor is made using the silicon germanium technology and they provide the similar DC RF efficiency as the transistors provide with the help of these group 3 and group 5 materials, but they are made at relatively low cost and with relatively low complexity in the manufacturing process.

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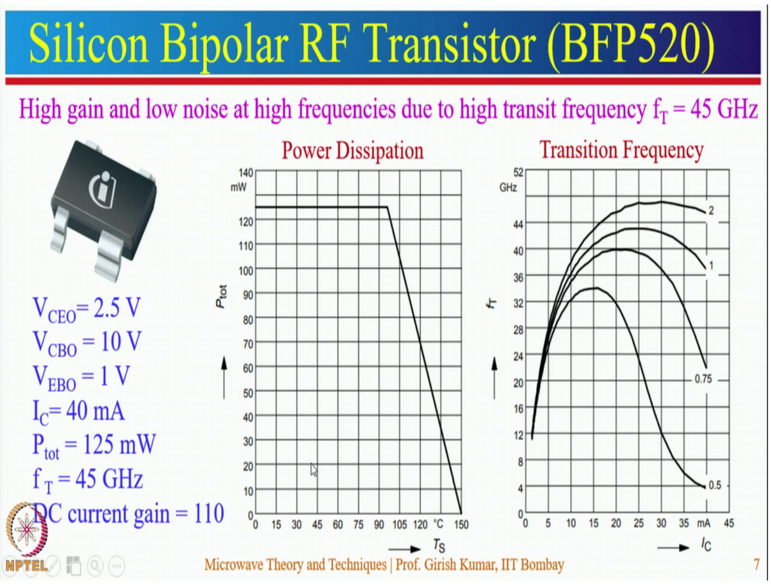

Silicon Bipolar RF Transistor (BFP520)

High gain and low noise at high frequencies due to high transit frequency $f_T = 45$ GHz

Power Dissipation

Transition Frequency

$V_{CEO} = 2.5$ V
$V_{CBO} = 10$ V
$V_{EBO} = 1$ V
$I_C = 40$ mA
$P_{tot} = 125$ mW
$f_T = 45$ GHz
DC current gain = 110

Till now, we just discussed about the operation of the bipolar transistor. So, here is the example of the practically available RF transistor; its name is BFP520. It provides higher gain and low noise and it the transition frequency of this transistor is 45 gigahertz. So, it is fairly good. Now, as I mentioned that the performance of this transistors degrade with temperature; so, here I have shown the variation of the power with respect to temperature.

It provides the 125 milliwatt power to 100 degree centigrade and the transition frequency for this transistor is 45 gigahertz for V CE is equal to 2 volts. Here, I have also listed down few other specifications like reverse voltage and the forward voltage and the output current of these transistor. So, it provides a decent gain of around 20 dB.

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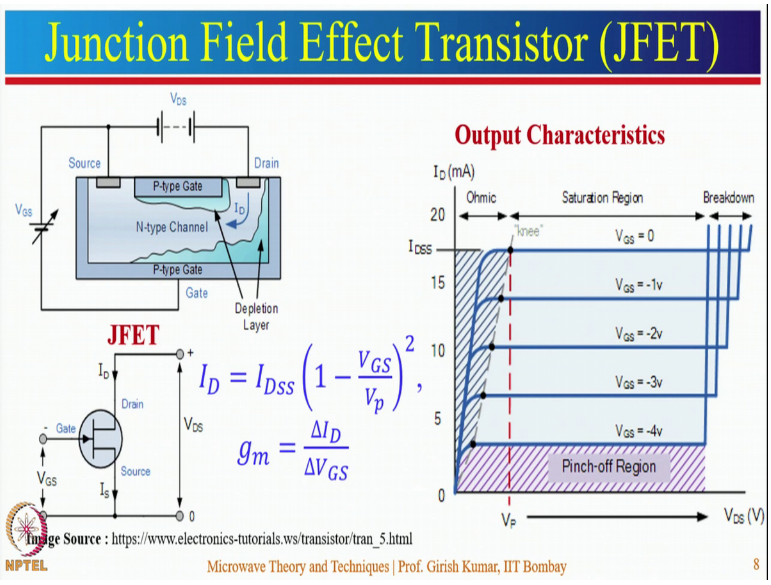

## Junction Field Effect Transistor (JFET)

$$I_D = I_{Dss}\left(1 - \frac{V_{GS}}{V_p}\right)^2,$$

$$g_m = \frac{\Delta I_D}{\Delta V_{GS}}$$

Image Source : https://www.electronics-tutorials.ws/transistor/tran_5.html

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Till now, we discussed about the bipolar junction transistors. So, this transistor suffers from the minority carrier affect. The next type of transistor is a Field Effect Transistor. They are the unipolar device; that means the current conduction in the field effect transistor is due to only one type of charge carriers. It could be either electron or hole depending upon the type of the channel. So, in case of n type channel the charge carriers will be electron and in case of p type channel charge carriers will be hole.

Now, one of the commonly used Field Effect Transistor at low frequency is Junction Field Effect Transistor. So, in case of Junction Field Effect Transistor, the structure is shown here to p type of lightly doped regions are diffuse into n type of channel and then, a metallic terminal is deposited in at these terminals. This is known as gate and there to other metallic terminals using the Ohmic contacts; they are known as Source and the Drain.

Now, if you see in this particular configuration, if you do not apply any bias voltage between the gate and the source terminal which is known as the input terminal, then there will be a path for electrons to flow from source to drain when you apply even a very small drain to source voltage. So, the maximum current will flow when V DS is very small and it will again increase if you increase the value of V DS. Now, if you apply a reverse bias voltage at these junction V GS; that means, the negative voltage is applied at the gate terminal the depletion region will try to increase.

Now, if you increase this reverse bias voltage further, there will be a situation that these 2 regions will touch each other. So, there will not be any passage to flow of electrons. So, there will not be any current and the current will reduce to 0. So, the current in this transistor is given by this expression I D is equals to I DSS 1 minus V GS by V p square; here V p is the Pinch-off voltage.

So, the situation when these depletion region touches each other this situation is known as the Pinch-off situation and the voltage V GS at that particular moment is known as the Pinch-off voltage and V GS is the reverse bias voltage along the gate to source junction and I DSS is the maximum current when no reverse bias voltage is applied. There is one more term trans conductance. So, trans conductance is an measure of change in output current I D with respect to change in the input voltage V GS for a constant value of V DS. Now, if you try to draw the output characteristics of this transistor; that means, the variation of I D with respect to variation in drain to source voltage you will the curves like this.

Here, this represents the Pinch-off region and these region represent the Ohmic region. In this region, there will not be any flow of current; however, in this region the field effect transistor will act like a voltage controlled resistor and this region is the saturation region. In this region, the drain current will be independent of the variation in the output voltage and the amplifier should operate in this region, if this if it is to be used for the amplification purpose.

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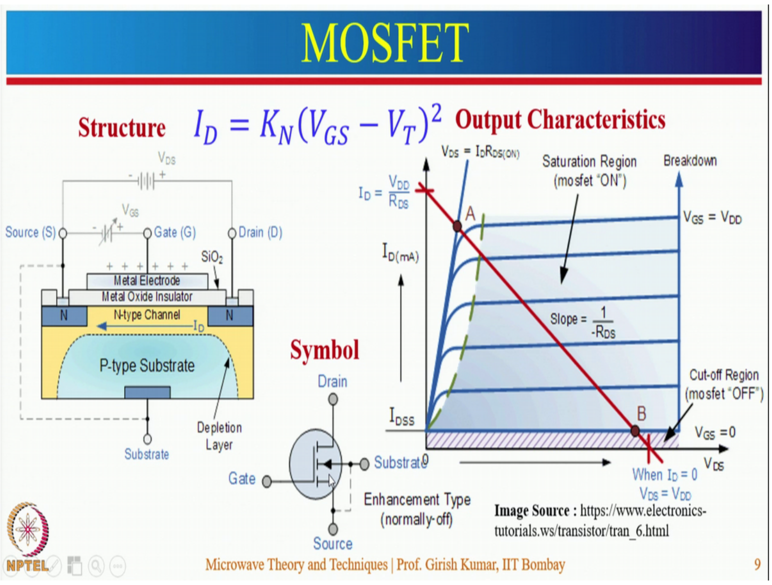

# MOSFET

**Structure** $I_D = K_N(V_{GS} - V_T)^2$ **Output Characteristics**

**Symbol**

**Image Source :** https://www.electronics-tutorials.ws/transistor/tran_6.html

The next type of transistor is the Metal Oxide Field Effect Transistor. In this transistor, the gate is separated from the channel by an insulating oxide layer; generally it is off silicon oxide. So, due to the insertion of silicon oxide, it provides very high gate capacitance and the impedance of these transistors will be very high maybe up to of the order of mega ohm. Now, if you see here this MOSFETs are divided into 2 categories; one is known as the Depletion MOSFET and other one is Enhancement type MOSFET.

So, Depletion type MOSFET there is a channel between the source and the drain terminal. So, there will be a flow of current when you do not apply any bias voltage between the gate and the source. So, there will be flow of current. Now, if you apply a negative bias voltage, it will try to ripple the electrons away from this channel. So, the current will reduce or if you apply a positive bias voltage, it will attract the electrons. So, the current will increase. So, the Depletion type MOSFET is similar to the Junction Field Effect Transistor.

The next type of transistor is the Enhancement type MOSFET. In this the channel, doping is either very light or there is no doping; that means, the channel is either undoped or it is lightly doped. So, in this case there is no flow of current when you use these Enhancement type transistors. So, if you apply a positive bias, in that case it will try to attract the electrons and the electrons will gathers in this region and they will try to form a channel. So, when the gate to source voltage is greater than the threshold voltage, it will form a channel between the drain and the source terminal and the current conduction will take place from drain to source.

Now, if you increase the voltage further the current will increase. Similarly, if you take negative gate voltage, in that case it will repel the electron and the current will be 0. So, now, output characteristics of these transistors are drawn. Here, this reason represents the cutoff region, this region represents the linear region or triode region and this is the saturation region. It is similar to the JFET region.

So, in this region the drain to source voltage should be less than the difference of V GS and V T; however, in this region the drain to source voltage should be greater than the difference of V GS and V T and the transistor should operate in this region for amplification purpose. Now if this transistor is to be used in the circuit, then they are presented by this symbol. Here, this broken line represents that there is no flow of current in these type of device.

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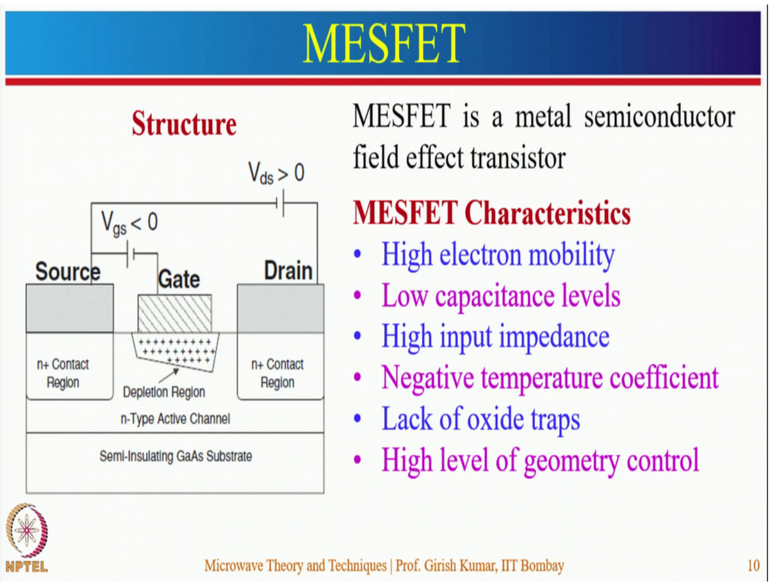

## MESFET

**Structure**

MESFET is a metal semiconductor field effect transistor

**MESFET Characteristics**

- High electron mobility
- Low capacitance levels
- High input impedance
- Negative temperature coefficient
- Lack of oxide traps
- High level of geometry control

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Now, these transistors do not provide desirable performance at higher frequencies due to the internal capacitance of the transistors. So, this capacitance should be reduced. The major component is due to the gate capacitance and which is due to the oxide layer in the transistor. Now, if you replace this oxide layer by simply gate semiconductor junction, then that type of semiconductor is known as the Metal Semiconductor Field Effect Transistor. So, here the gate is placed on the top of the semiconductor junction. It behave in the similar way as the MOSFET and JFET does by applying the negative k 2 source voltage, it forms the depletion region and it restricts the flow of current. So, the current will reduce.

Now, due to the metal semiconductor region, it provides relatively fast recovery time. So, they are relatively faster and they can operator up to relatively high frequency range. So, here is the structure of gallium arsenide base MESFET and it provides better performance over other transistor due to the higher mobility of these materials. So, they provide the various better characteristics over other transistors; they are high electron mobility, low capacitance level, high input impedance and they providing negative temperature coefficients and there is lack of oxide trap in these transistors. Similarly, there is a high level of control in this type of geometries.

Now, one of the critical parameter in this transistor is the gate length. By reducing the gate lengths, its maximum operating frequency can be varied. So, if the gate length is less, the maximum frequency will be more and if the gate width is reduced in that case the noise performance will prove and if the gate width is high, this will be a better transistor for the high power application. Now, these transistors are also not very suitable for very high frequency range.

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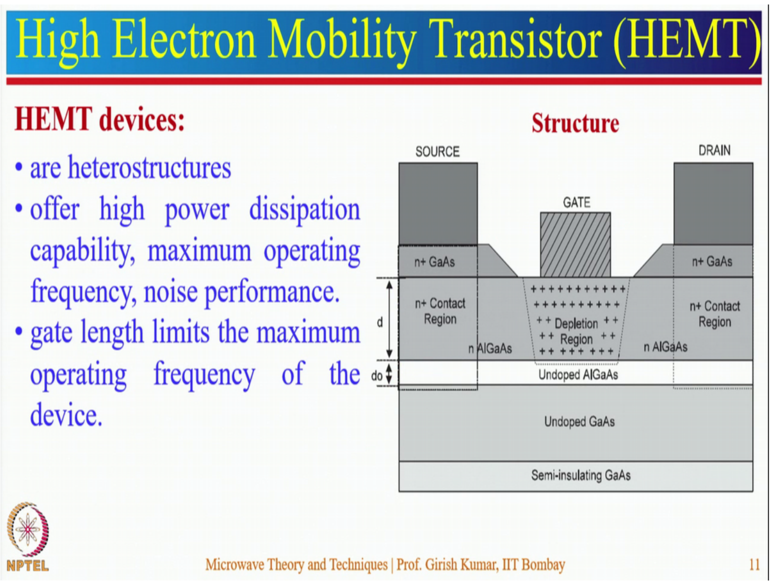

High Electron Mobility Transistor (HEMT)

**HEMT devices:**

- are heterostructures
- offer high power dissipation capability, maximum operating frequency, noise performance.
- gate length limits the maximum operating frequency of the device.

**Structure**

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So, there is a improvement on transistor by making the changes in the channel. So, they are known as high electron mobility transistors they are made of heterostructures. In these transistors, the channel is made by using different type of materials. So, here is a structure of high electron mobility transistor. They provides very high power dissipation capability and maximum operating frequency and the noise performance over the MESFET and this better performance is due to the higher mobility of electron in these transistors.

Now, in the same way as it was the case of as MESFET, here also the gate length is the critical parameter and this decides the maximum operating frequency and in these transistors, the trans conductance is directly proportional to the gate width and inversely proportional to the gate length. There is one more critical parameter in this that is the undoped gallium arsenide layer with and the n type dope aluminium gallium arsenide width. So, therefore, microwave region this width should be between 0.02 micron to 0.3 micron, (Refer Time: 27:33) in this region, the width should be of around 5 nanometer.

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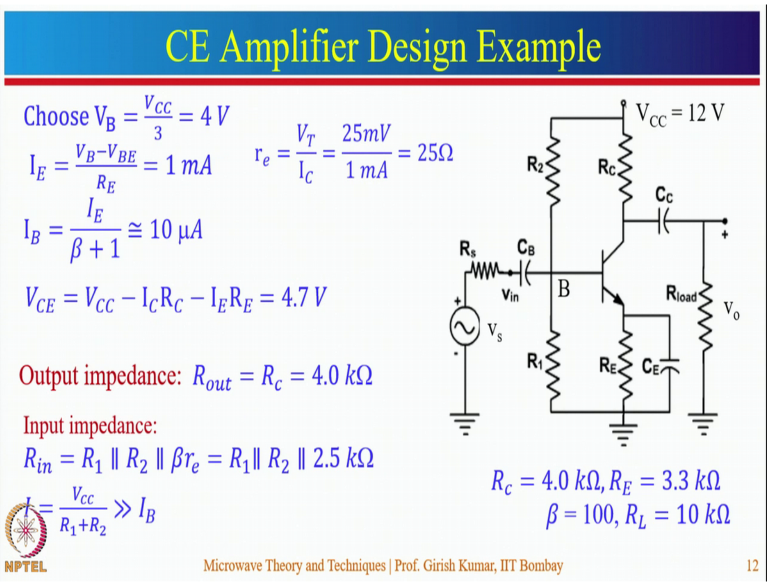

CE Amplifier Design Example

Choose $V_B = \frac{V_{CC}}{3} = 4\,V$

$I_E = \frac{V_B - V_{BE}}{R_E} = 1\,mA$ $\quad r_e = \frac{V_T}{I_C} = \frac{25mV}{1\,mA} = 25\Omega$

$I_B = \frac{I_E}{\beta + 1} \cong 10\,\mu A$

$V_{CE} = V_{CC} - I_C R_C - I_E R_E = 4.7\,V$

Output impedance: $R_{out} = R_c = 4.0\,k\Omega$

Input impedance:

$R_{in} = R_1 \parallel R_2 \parallel \beta r_e = R_1 \parallel R_2 \parallel 2.5\,k\Omega$

$I = \frac{V_{CC}}{R_1+R_2} \gg I_B$

$R_c = 4.0\,k\Omega, R_E = 3.3\,k\Omega$

$\beta = 100, R_L = 10\,k\Omega$

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Now, we will discuss about the design example of common emitter amplifier. Now, before going into these, the let us compare the field effect transistors with the bipolar junction transistor. So, field effect transistors occupy relatively less area. So, they are more suitable to be integrated in the I C form and they do not suffer with the minority carrier fix. Similarly, they have the negative temperature coefficient. So, they do not suffer with the temperature variations. Hence, these devices do not go into the thermal runaway situation and the input impedance of these transistors are also high of the order or mega ohm. However, in case of bipolar junction transistor the impedance is of the order of kilo ohm.

Now, we will take an example of Common Emitter Amplifier. This is the example of Common Emitter Amplifier using voltage divider bias configuration. The supply voltage is 12 volt. Now, we should choose the operating point in order to this configuration as an amplifier. So, why should choose the voltage over here in such a way so that its value should be one-third and it will depend upon the value of these resistors. So, let us take V B as V CC by 3 that will be 4 volt and if you see here, this will corresponds to voltage drop. So, this will be 4 minus 0.7 that is 3.3. Now, if you divide this voltage by emitter resistance, this will give us the emitter current and that will come out to be 1 milliampere.

Now, we know that the emitter current is given by beta plus 1 times of I B, from there you can calculate the base current and the base current will be 10 microampere. Now, if you try to calculate the collector to emitter voltage V CE. So, that will be V CC minus I C R C minus I C R E. So, I C and I B will be approximately same. If you put the value of R C and R E in this expression, you will get the value of 4.7 volt. Now, if you see here this is the R E and R E is given by V T upon I C; here, V T is the thermal voltage at room temperature its value is 25 milli volt. Now, if you put the value of I C and V T you will get the impedance of 25 ohm.

Now, let us calculate the output and input impedance and other parameters of this particular configuration. To calculate the output impedance just short circuit all the voltage sources and open circuit all the current sources. Now, if you short circuit and you see the impedance at output terminal, you will see that the R out R C and that is equal to 4 kilo ohm. And now, to calculate the input impedance this will be the impedance seen at this end. So, it will be a parallel combination of R 1 and R 2 and the impedance seen by this transistor.

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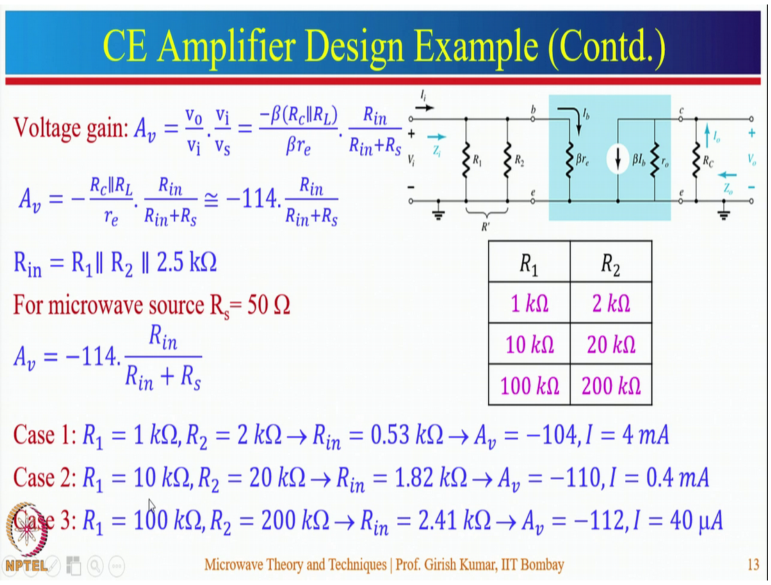

## CE Amplifier Design Example (Contd.)

Voltage gain: $A_v = \frac{v_o}{v_i} . \frac{v_i}{v_s} = \frac{-\beta(R_c \| R_L)}{\beta r_e} . \frac{R_{in}}{R_{in}+R_s}$

$A_v = -\frac{R_c \| R_L}{r_e} . \frac{R_{in}}{R_{in}+R_s} \cong -114 . \frac{R_{in}}{R_{in}+R_s}$

$R_{in} = R_1 \| R_2 \| 2.5\ k\Omega$

For microwave source $R_s$ = 50 Ω

$A_v = -114 . \frac{R_{in}}{R_{in} + R_s}$

| $R_1$ | $R_2$ |
|---|---|
| $1\ k\Omega$ | $2\ k\Omega$ |
| $10\ k\Omega$ | $20\ k\Omega$ |
| $100\ k\Omega$ | $200\ k\Omega$ |

Case 1: $R_1 = 1\ k\Omega, R_2 = 2\ k\Omega \rightarrow R_{in} = 0.53\ k\Omega \rightarrow A_v = -104, I = 4\ mA$

Case 2: $R_1 = 10\ k\Omega, R_2 = 20\ k\Omega \rightarrow R_{in} = 1.82\ k\Omega \rightarrow A_v = -110, I = 0.4\ mA$

Case 3: $R_1 = 100\ k\Omega, R_2 = 200\ k\Omega \rightarrow R_{in} = 2.41\ k\Omega \rightarrow A_v = -112, I = 40\ \mu A$

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So, here I have drawn the R E model of this transistor. So, the input impedance will be the parallel combination of R 1 R 2 and beta R E. So, beta R E is because of the transistor. So, if you see here and put the value of beta and R E, you will get this particular expression.

There is one thing to be noted in this configuration, it is assume that the current going in this particular direction that is the base current is very less as compared to the current going in this particular loop. So, the current going in this loop will be given by I equals to V CC upon R 1 plus R 2. Now, if you calculate the voltage gain using this model, we know that the voltage gain is represented by v naught by v s and if you bifurcate this in these 2 expressions like v naught upon vi into vi by vs. So, we know that v naught will be given by this. So, here v naught will be minus beta I b times of R C in parallel with R L you can neglect R naught because the value of this R naught is very high.

So, it will be beta times of I b into R C parallel with R L and vi will be this. So, that will be beta into r e into I b. Now, you see the I b and beta, they will cancel out and for this particular expressions vi will be if you equate this equivalent impedance by R in and this source voltage is connected here, then the voltage along the vi is given R in upon R in plus R s using this simple voltage divider rule.

And now, if you try to simplify this expression you will get the voltage gain like this and further if you put the value of R C and R L and r e, you will get the expression this. Now here, the source resistance for the microwave region is 50 ohm because all the sources have the 50 ohm impedance. Now the other parameter that decides this gain is the R in and that depends upon the value of R 1 and R 2. Now, what should be the value of R 1 and R 2? So, we know that this will be less than 1. So, our purpose should be that this should be S close to 1 and for that we should choose R 1 and R 2 as high as possible, but as I mentioned here, this R 1 and R 2 also limits the current. So, one should choose the point accordingly.

So, let us take here 3 cases when R 1 and R 2 are 1 kilo ohm and 2 kilo ohm and for the second case, when they are 10 kilo ohm and 20 kilo ohm and for the third case, they are 100 kilo ohm and 200 kilo ohm. For the first case if you calculate the R in, it will, come out to be 0.53 kilo ohm and if you put this value in this expression, the value of the voltage gain will be 104. So, it has reduced the voltage can significantly. Now if you see the value of the current going in the R 1 and R 2 is 4 milliampere. So, it is significantly greater than the base current because base current is ten microampere.

For the second case, the voltage gain will be minus 110. So, it is better than this particular case and the current in this case is 0.4 milliampere. So, this is also relatively much higher as compared to base resistance and in the third case, if you see R in is 2.41 kilo ohm and the voltage gain for this configuration is even close to 140. But the current, if you see here is 40 microampere which is not much higher than the base current. So, this case cannot be considered. So, the most appropriate choice for this case is R 1 is equals to 10 kilo ohm and R 2 equals to 20 kilo ohm.

So, one should choose the value of these parameters by keeping in mind different considerations of the common emitter amplifier configurations. Now, we will talk about the transistor applications.

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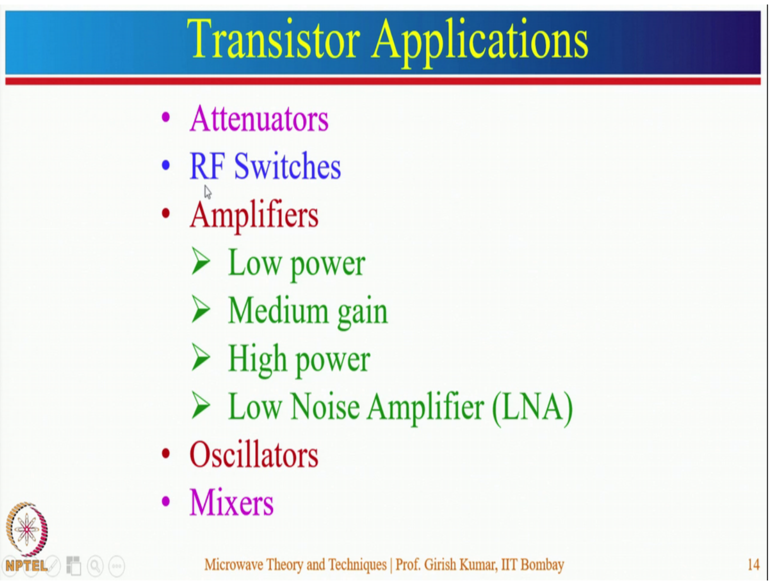

## Transistor Applications

- Attenuators
- RF Switches
- Amplifiers
    - Low power
    - Medium gain
    - High power
    - Low Noise Amplifier (LNA)
- Oscillators
- Mixers

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So, these transistors can be used in attenuators, RF circuits, amplifiers. In amplifiers with the help of transistors, you can make the low power amplifier, medium gain amplifiers, high power amplifiers. Similarly, you can also make low noise amplifier and gain with the help of transistors; you can make oscillators and mixers. So, in the previous lecture, you have studied the use of transistors in variable attenuator and in RS switchers and in the coming lectures, you will see the use of these transistor in amplifier oscillators and other circuits.

Now, to conclude this, we started with microwave transistors and these are of 2 types. We started with Bipolar Junction Transistor, then we saw the limitations of Bipolar Junction Transistors; to overcome them limitations of low frequency bipolar junction transistor, the Heterojunction Bipolar Transistors were introduced. They can operate up to very high frequency range be up to of the order of 100 gigahertz. Then, we saw the other type of transistor that is known as the Field Effect Transistor.

After that we saw the low frequency transistors that are Junction Field Effect Transistor and the Metal Oxide Field Effect Transistor and we saw that the internal parameters of these transistors limit the frequency of these transistor. So, to improve the frequency, we studied the next type of transistor that is Metal Semiconductor Field Effect Transistor. Here, the reverse bias PN junction or the oxide layer of the transistor is replaced by the metal semiconductor junction. So, they can operate up to relatively very high frequency range and they provides relatively high gain. These MESFET cannot operate up to very high frequency range.

So, the next type of transistors were introduced that are known as high electron mobility transistors and in these transistors the channel is made using different type of semiconductor and these transistors provides the better performance over the other transistors. Now, I mean all these transistors the Heterojunction Bipolar Transistors are the best option, if you want to operate at high frequency range.

So, in the next lecture you will see the application of these transistors in amplifiers.

Thank you very much, bye.