Integrated Circuits, MOSFETs, OP-Amps and their Applications
Prof. Hardik J Pandya
Department of Electronic Systems Engineering
Indian Institute of Science, Bangalore

Lecture – 27
Introduction to Oscillator

Hello, in this module and it actually it is a set of modules for this particular lecture, we will see how we can design oscillators. So, until now what we have seen we have seen amplifiers; we have seen the filters; and then we must see how we can design oscillator. So, we have seen several types of filters right in the last lecture; right from low pass, high pass, band pass, band reject, amplifiers, inverting, non-inverting, summing amplifier, comparator a differential amplifier. So, we see this is how we are learning about how we can use op amp for several applications.

So, when you talk about oscillations, what oscillations means right. Oscillations is something vibrating is something vibrating right that also causes the oscillation. So, how we can generate this vibrating motion or how we can generate if you talk about electronics, how we can generate this vibrating signal right with the which is constant, which is constant right. So, if something is oscillating at a constant frequency, we can generate oscillator.

How we can arrive to this constant frequency, how we can design a circuit that will generate this constant frequency right and how the op amp will play a role in designing the oscillators, so that we will see in this particular module. Let us see what exactly oscillators are. So, this class is about oscillators and second part would be about noise all right. So, right now the modules we will see what the oscillators are, this is class number 12.

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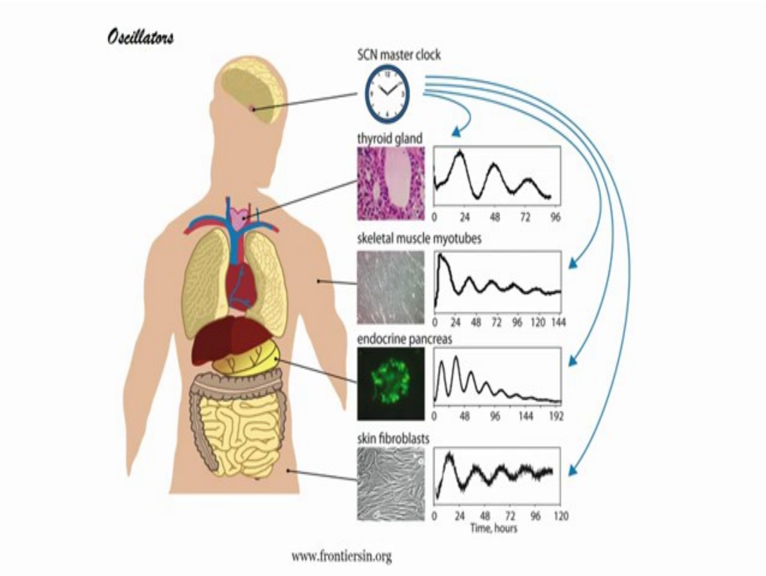

So, when you talk about oscillators have you ever thought about our body right. So, we have a brain right; all of us have a brain, I hope; and we use it, we use it. So, this is nothing but a master clock; it is our master clock right. It tells us when to sleep, when to be awake, when we are hungry, this and that, everything is controlled by this brain right; it is a master clock.

And then we have several parts in our body which forms a signal which looks like a oscillation signal for example, if you take a thyroid gland or you take a skeletal muscles myotubes or you can take endocrine pancreas or you can take skin fibroblasts everything you will see a certain pattern see certain patterns right you see. So, there are the oscillations are everywhere all right, the oscillations are everywhere. If you say about energy, energy is a positive, energy negative energy is nothing but the oscillations around us oscillations around us.

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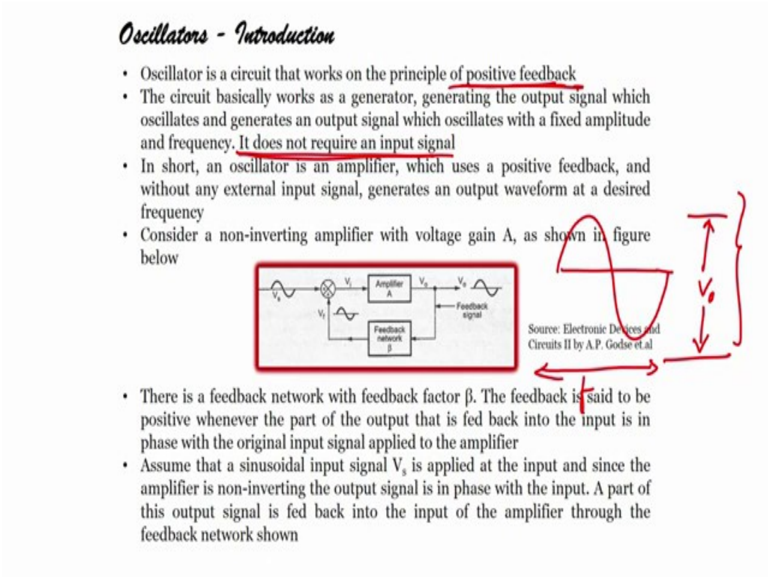

So, let us see kinds of oscillate and how we can design this oscillator. So, first before we understand how we can design the oscillator, the most important point is that when we have to design a oscillator we have to use positive feedback we have to use positive feedback; in case of amplifiers we were using negative feedback. So, oscillator is a circuit that works on the principle of positive feedback.

The circuit works as a generator generating the output signal, which oscillates and generates an output which oscillates with a fixed amplitude and frequency. It does not require an input signal it does not require input signal; that means, what it says that we can generate an output which a particular amplitude particular amplitude peak to peak voltage and a frequency and a frequency right it is a fixed amplitude and fixed frequency fixed frequency right with the help of an oscillator all right that is a circuit that can generate output signal with fixed amplitude and fixed frequency.

Second point it will not require or it does not require any input signal. We will see why we will see why ok. Two things you must understand about the oscillator. In short, an oscillator is an amplifier, which uses a positive feedback, and without an external input signal, generates an output for waveform at a desired frequency. So, if I consider a non-inverting implemented voltage gain A, if I consider this amplifier volt voltage gain A, what we can see there is a feedback network with feedback factor β right.

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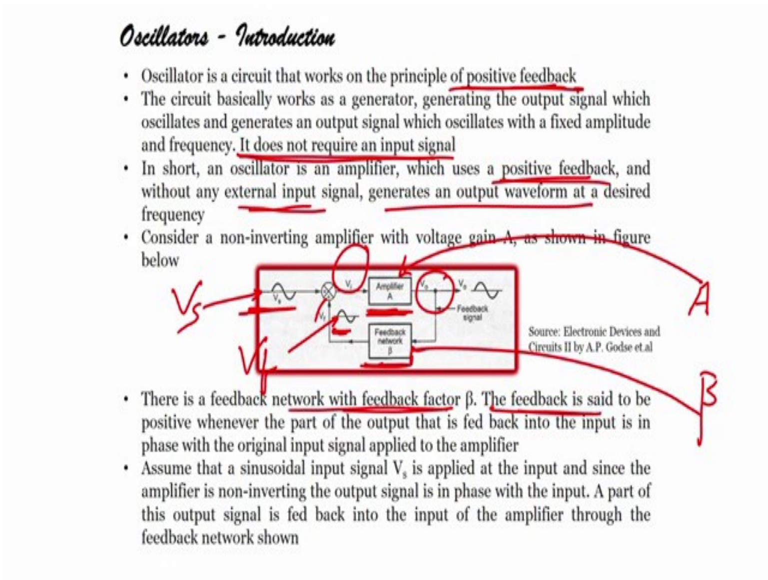

There is a amplifier here with voltage gain A. There is a feedback network here which we call β right. The feedback it is said to be positive. Whenever; the part of output that is fed and into the input is in phase with the original input signal applied to the amplifier. What does it mean? Right, see the sentence what it says that the feedback the feedback is said to be positive is said to be positive when the part of the output, this is output right, when the part of the output is fed back to the input, this is the input right.

In phase, in phase means your input is this right their output can be in phase or out output can be out of phase, and this part is feedback to the input that should be in phase with the input, it should be in phase. The output the part of the output that we are feeding back to the oscillator should be in phase. So, you see here is the signal.

See this schematic, schematic is this is your input signal right and this is your feedback signal input voltage or input signal Vs feedback signal Vf all right. This Vi would depend on Vs + Vf or Vs - Vf. Then we have amplifier we output voltage this output voltage is feedback to the feedback network and that goes back to the input signal right easy, very easy right, super easy. So, what we have learned we have learned that when there is a feedback network meter and when we apply a output voltage, a part of output voltage is feedback to the input it is in phase and that is why it is a positive feedback. It is said to be positive.

Next, next is assumed that a sinusoidal input signal V s is applied to the input at since amplifier is non-inverting the output signal is in phase with input a part of output signal is fed back into the input of the amplifier through the feedback network shown in figure this is exactly what we are talking about. Here we have considered the amplifier is your non-inverting amplifier. Non-inverting amplifier means your output would be in phase with the input in phase that means. If it is 0 degree, this is also 0 degree right. And if it is an inverting amplifier, then your output would be out of phase, out of phase 180 degree out of phase.

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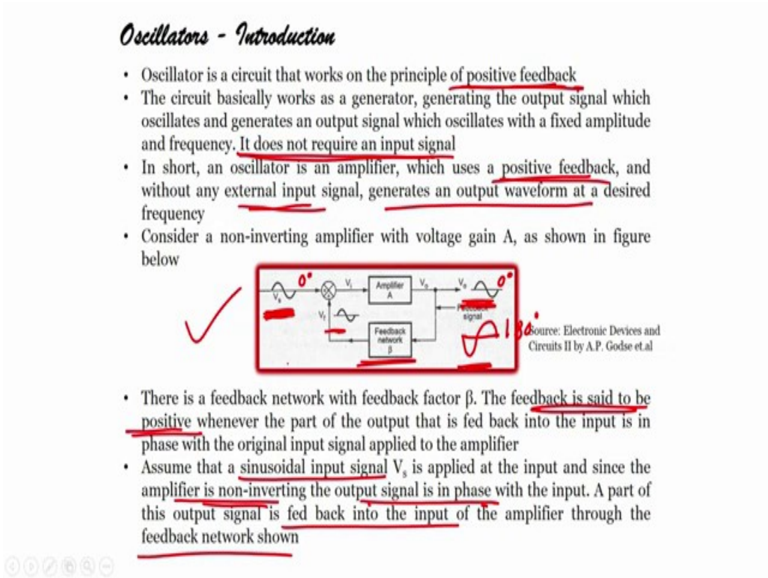

If I see this signal and if I see the input signal my output is 180 degree out of phase, but here what we have considered we have considered that the amplifier that we are using is a non-inverting amplifier. So, your output would be in phase to the input signal right this much is easy. So, let us quickly see once again what this slide shows us this slide shows us few important points.

One is that the oscillator uses positive feedback. Second is that the oscillator is a circuit that generates a fixed a fixed amplitude and frequency fixed, amplitude of frequency, generates a signal with a fixed amplitude and frequency right. Third thing the feedback the feedback is said to be positive or when we can see it is a positive when the part of the output signal that is fed back to the input is in phase in phase. So, these things we have learned in the introduction to the oscillators.

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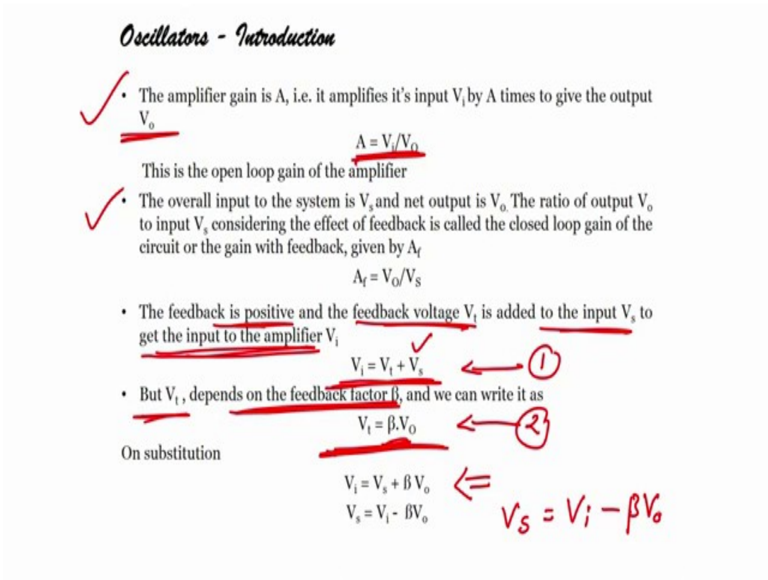

Now, the amplifier gain that is A gain that is it amplifies the Vi by A times to give output voltage V_o. And see this circuit schematic. Here the we are just talking about this part. So, what we see is, amplifier input is Vi, output is Vo. So, how we can define A, we can define A as V_i/ V_o. This is the open loop gain because if I just consider this square right rectangle in which my circuit is there then there is no feedback and that is why it is an open loop gain. It is an open loop gain.

So, what we see is that the amplifier gain is A right that is amplifies the input signal V_i by A times to give the output signal V_o or we can write A equal to V_i/V_o, this is the open loop gain amplifier. The overall input system is V_s and the net output is V_o. So, let us go back.

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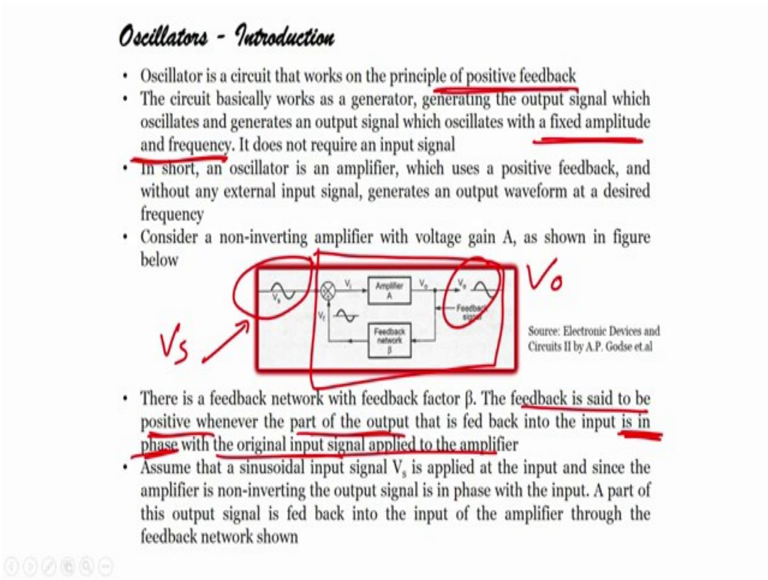

And now what we are saying is that the overall input to this oscillator right is V_s. And the output is V_o correct; overall is V_s this is the input signal amplifier, but overall is V_s, so V_s and V_o. So, in this particular case, the overall system is V_s, output V_o the ratio of V_o to V_s is considered effect of feedback it is called the closed loop gain of the circuit; and it is given by $A_f=V_o/V_s$.

In this case, when we consider signal V_s and we consider the signal V_o then we have to understand that this V_s and this V_o are dependent on the feedback are dependent on the feedback right. Because depending on the V_f your V_s that is applied to the amplifier would change right. And now it is a closed loop amplifier because we have not close the loop and here we can have gain

$A_f= V_s/V_o$

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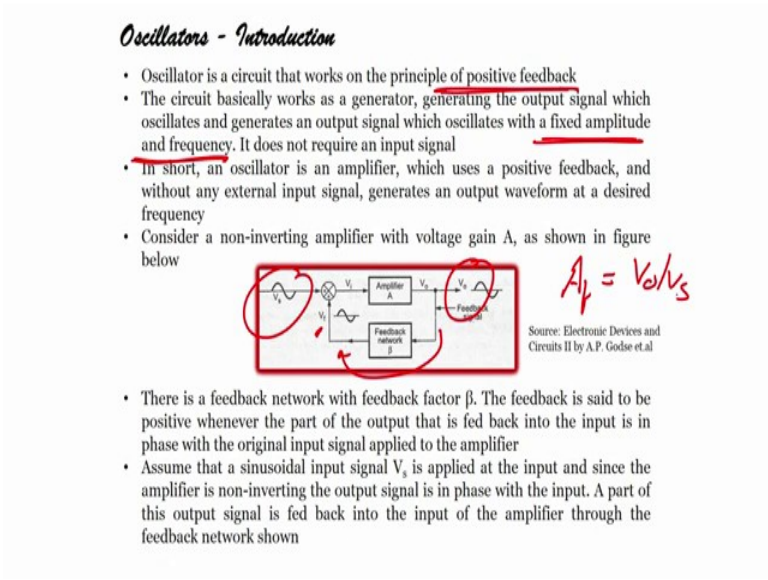

Now, we can also write gain equals to V_o/ V_i. So, this one is done this is done. Let us see another one the feedback is positive, and the feedback voltage V_t is added to the input signal V_s to get the input to the amplifier V_i which is correct.

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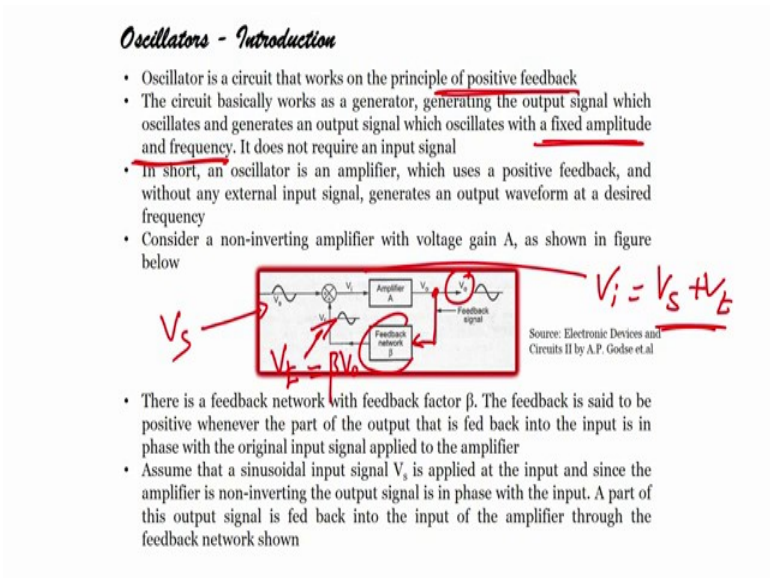

Why, because if I see it my feedback signal is V_t my input signal is V_s, then my V_i would be nothing but $V_i = V_s+V_t$; why plus because the signal is in phase and that is what we have written V_i equals to feedback signal plus input signal. This V_i is the input to the amplifier. But V_t that is feedback signal depends on the feedback factor β because you see again this signal depends on the feedback factor β. That is why what we had to write $V_f=\beta V_o$. So, what we will have this is if I say this is equation 1, this is equation 2. Substituting equation 2 in equation 1, what I have; I have

$$V_i=\beta V_o;$$

$$Vs=V_i- \beta V_o.$$

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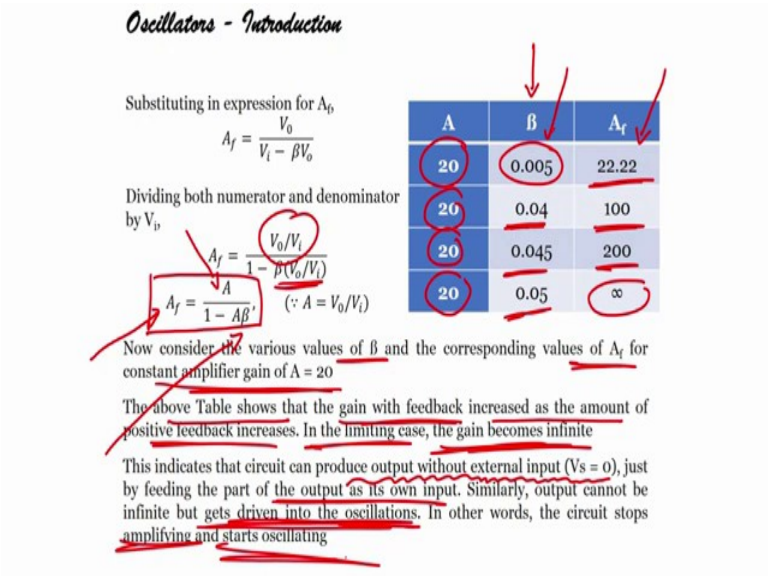

Substituting in expression for A_f,

$$A_f = \frac{V_0}{V_i - \beta V_o}$$

Dividing both numerator and denominator by V_i,

$$A_f = \frac{V_0/V_i}{1 - \beta(V_o/V_i)}$$

$$A_f = \frac{A}{1 - A\beta}, \qquad (\because A = V_0/V_i)$$

Now consider the various values of ß and the corresponding values of A_f for constant amplifier gain of A = 20

The above Table shows that the gain with feedback increased as the amount of positive feedback increases. In the limiting case, the gain becomes infinite

This indicates that circuit can produce output without external input (Vs = 0), just by feeding the part of the output as its own input. Similarly, output cannot be infinite but gets driven into the oscillations. In other words, the circuit stops amplifying and starts oscillating

See again we if we closely see what we have done, we have we have derived the equation of A_f the equation of A_f right. Now, here we are we are kept a constant of 20, and we are increasing the β like you see here this is 0.5 is less than 0.04, 0.04 is less than 0.045 is less than 0.5 that means, we are increasing β correct. On increasing β, we see increase in A_f to the point that increase reach to infinite. Now, it cannot be infinite; that means, it will start oscillating. So, in other words the circuit will stop amplifying and start oscillating right. It will stop amplifying and start oscillating here. What important things that we had to learn from this slide, but only a part of output signal is fed feedback to the input or β is extremely small, β is extremely small.

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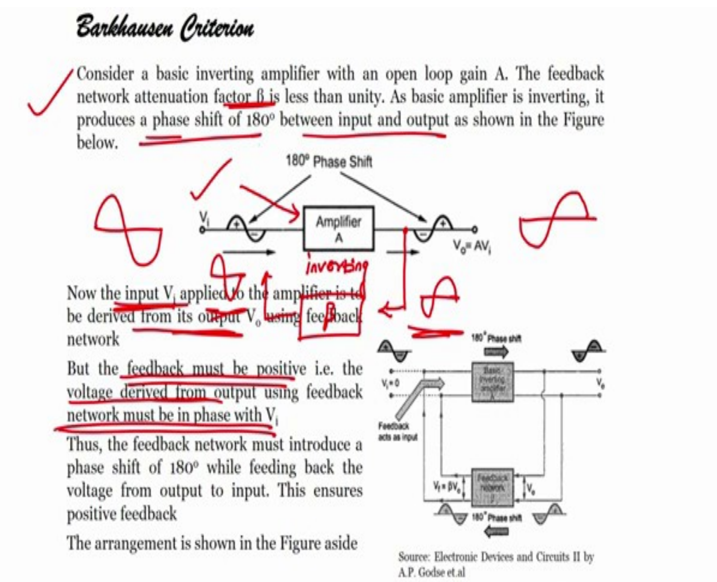

So, to understand the oscillator we must understand a very important criteria called Barkhausen criterion. So, what is that Barkhausen criterion, and why we must learn to understand the oscillator to understand the oscillator all right. So, we will see today what exactly is the Barkhausen criterion, and why it is important to understand so to get the idea how the oscillations would work all right. So, if you see the screen what we find is that considering a basic inverting amplifier with an open loop gain A, the feedback network attenuation β is less than a unity as a basic amplifier inverting it produces a phase shift of 180 degree between input and output as shown in figure right. One thing we have seen what that if I apply input signal, and if I consider my amplifier to be inverting, then my output signal would be 180 degree out of phase with respect to input right, this is what is written for sentence ok. This is easy to understand.

Now, let us see now the input V_i is applied to the amplifier right V_i is applied to this amplifier is to be derived from its output voltage using feedback network. So, this feedback network should be there; some feedback network should be there right to with this V_o should be fed, and this would be fed to your V_i. So, that your V_s can be determined correct that is what we have seen. So, but the feedback must be positive right; that means, that if I feed part of this voltage if I feedback to the input of the oscillator, the phase here is 180 degree out of phase. But here I want same phase here I want same phase because it is a positive feedback, we have just seen. Here it is 180 degree out of phase here, I want same phase.

So, what is the return here that, but the feedback must be positive that is voltage derived from the output using the feedback network must be in phase with input V_i correct that we have seen does. The feedback network must introduce a phase shift of 180 degree.

It is very easy to understand what is saying is that if I apply input signal which is like this if I see output signal which is 180 degree out of phase, I have to I have to provide a part of the output signal back to the input through my feedback network β. This I know this we have seen right; part of the output is fed back to the input through feedback network β. So, part of the output how it looks like, like this.

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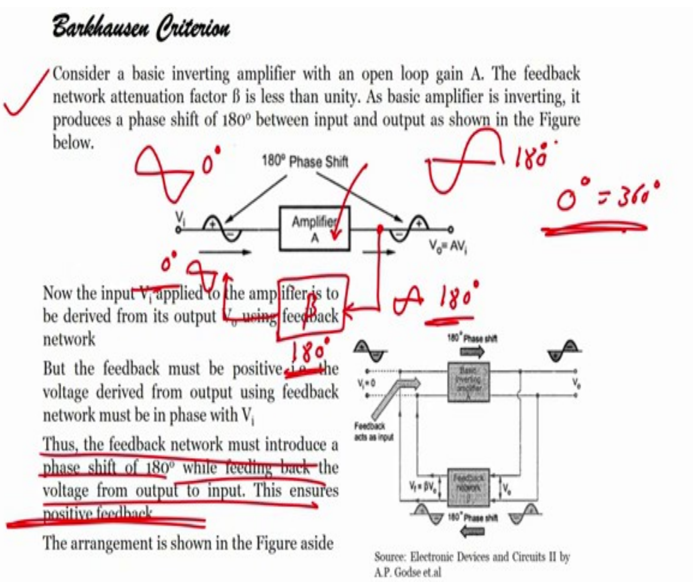

Now, this is 180 degrees out of phase right compared to the input, but we know that the input should be in phase., The part of the signal that is provided back to the input should be in phase. That means, my feedback that is provided back to the input should be 0 degree, but here it is 180 degrees. How can I make it 0 degree? So, this 180 degree if I introduce a phase shift of 180 degrees in my β, if I introduce a phase shift of 180 degree in my feedback network, then 180 degree plus 180 degree, there will be my 360 degree 360 degree is equal to 0 degree correct, 0 and 360 degree are same.

That means that my β that is feedback network should introduce a phase shift of 180 degree if my amplifier is an inverting amplifier which is causing my output to be out of phase with respect to input. That is why my output is 180 degree out of phase and then this output part of this output is fed back to the input through β which is feedback network it has to again have 180-degree phase shift which is provided by my feedback network β. This is what is written that the feedback network must introduce a phase shift of 180 degree, while feeding back the voltage from output to the input this ensures the positive feedback. And this arrangement whatever we are drawing here it is already shown in the figure here correct.

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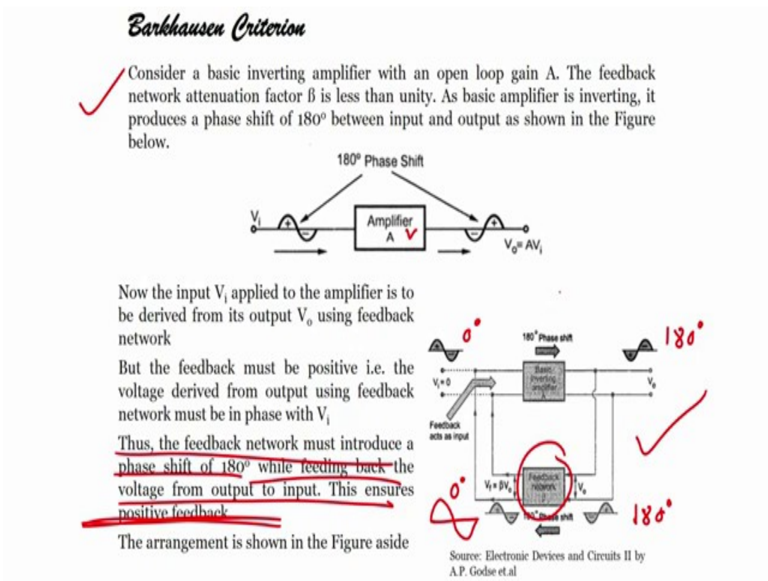

So, if we see input signal 0-degree, 180-degree phase shift because inverting amplifier, so 180-degree part of output is feedback to the input. This is 180-degree phase because these same voltage, which is V_o right, a part of the voltage. Here you see this is like 0-degree right. So, this phase shift, this phase shift is introduced by feedback network β correct. This is what is shown here, and this is how the things work. So, first thing we understood that inverting amplifier then what we are to use a feedback network which can introduce 180-degree phase shift.

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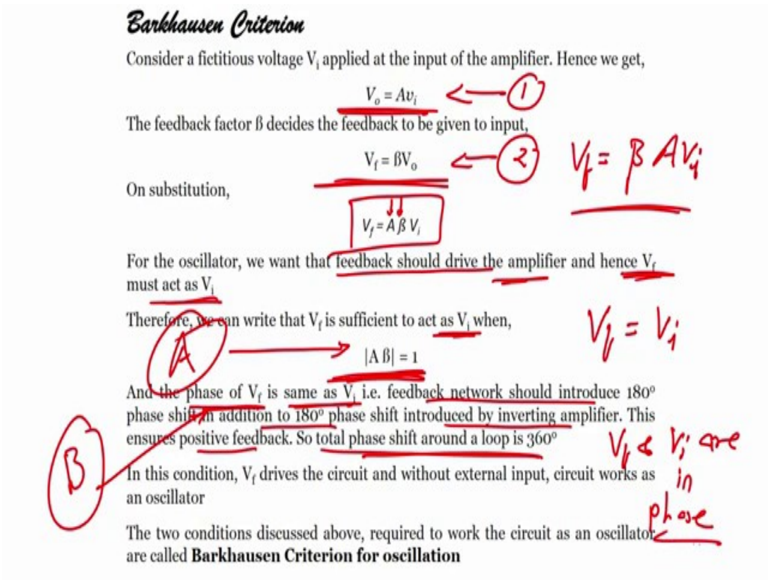

Now, considering a fixed voltage V_i applied to that the applied at the input of the amplifier what we get is V_o equals to $A*V_i$. The feedback network β decides the feedback to the to the given to the input. So, $V_f=\beta*V_o$. On substituting the value what we get, so we know this V_o=Vi we have $V_f=\beta*V_o$. For the oscillator we want that the feedback should drive the amplifier hence V_f must act as V_i correct. This is also easy for the oscillator and what we want is that the feedback should drive the amplifier. And hence V_f that is feedback voltage must act as an input voltage.

Therefore, we can write V_f is enough to act as V_i when we have $A\beta=1$ right. You see this feedback network right feedback voltage. Feedback voltage=gain*β*V_i. So, the, but in reality, what we want V_f should be equal to V_i right feedback voltage should drive the amplifier. So, to do that what is the what is the thing that we require that this A and β the mode of A*β should be 1.

Second thing the phase of V_f is same as V_i right. This is first thing all right, let us say A. Second is phase of feedback. So, we say be all right there is feedback network should introduce 180-degree phase shift in addition to 180 degree phase shift introduced by inverting amplifier if you are using inverting amplifier this ensures positive feedback. So, total phase safety is 360 degree or 0 degree; that means, my V_f and V_i are in phase are in phase correct. You got it. First thing is that my V_f should be equal to V_i and to get that to get that my Aβ should be equal to 1, so that is my first condition; my second condition is the V_f and V_i should have same phase right.

So, in this condition, we have driven a circuit and without external input circuit works as an oscillator. The above two conditions which are conditions condition one, so let me remove this. So, it is not confusing anymore. Let us say this is condition one; this is condition two right. The above conditions required to work the circuit as an oscillator are called the Barkhausen criterion for oscillation.

So, whenever somebody asks what are the Barkhausen criterion for oscillations, we can say that there are two criterias. First is that $|A*\beta|$ should be 1. Second condition is that V_f should be in phase with V_i or the feedback signal should be in phase with the input signal right. So, if we are using an inverting amplifier, feedback should introduce 180-degree phase shift; if we are using a non-inverting amplifier, feedback should not introduce any phase shift right.

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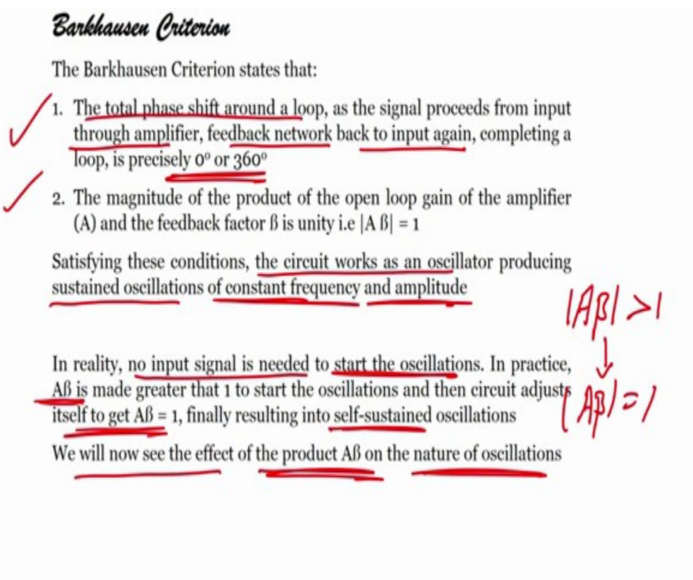

So, the Barkhausen criterion states that one the total phase shift around a loop is a signal proceeds from input through the amplifier, feedback network back to the input again completing a loop should be 0 degree or 360 degree right. Total phase shift should be 0 degree or 360 degree that is the first criteria. That means, if I apply an input signal my output signal is feedback through the feedback network to the input of the oscillator, then my output which is fed back through the feedback network should be in phase with the input signal that is my first condition right. So, if it my output voltage is out of phase, and my feedback network should provide a 180-phase shift; if my output is in phase with the input my feedback network does not require to provide any phase shift. So, two things you have to remember right.

Second thing is, first thing is this, second thing is the magnitude of the product of open loop gain of the amplifier and feedback network what is open loop gain of the amplifier A, what is feedback network β right. So, magnitude of the product of open loop gain of the amplifier and the feedback network should always be equal to 1. Why, because we have seen that V_f that is a feedback voltage=A*β* V_i and a V_i should be enough to drive the input signal to miss this condition V_f should be equal to V_i to meet that condition A*β=1. So, two conditions when you remember then you understand what exactly a bar is what exactly is a Barkhausen criterion and what does it states ok.

So, if you come back on the screen what you see is that if you can satisfy this both the conditions, if you satisfy first two condition, then the circuit works as an oscillator producing a sustained oscillations of cost constant frequency and amplitude. If you satisfy these conditions the circuit works as an oscillator producing sustained oscillation of constant frequency and amplitude. No input signal is needed to start the oscillation. In practice, A β is made slightly greater than one to start the oscillation and then it adjusted itself to equal to 1, finally resulting in a sustained oscillation or self-sustained oscillation right.

So, ideally there is no input required, but practically or in practice what we will do will have A*β should be slightly greater than one and then it comes back to A*β becomes equal to 1 once oscillation start the A*β becomes gets equal to 1. Now, we will see the effect of A*β on the nature of oscillations. So, now, once you know right how the things works, let us see how what the effect of A*β on the oscillations is ok.

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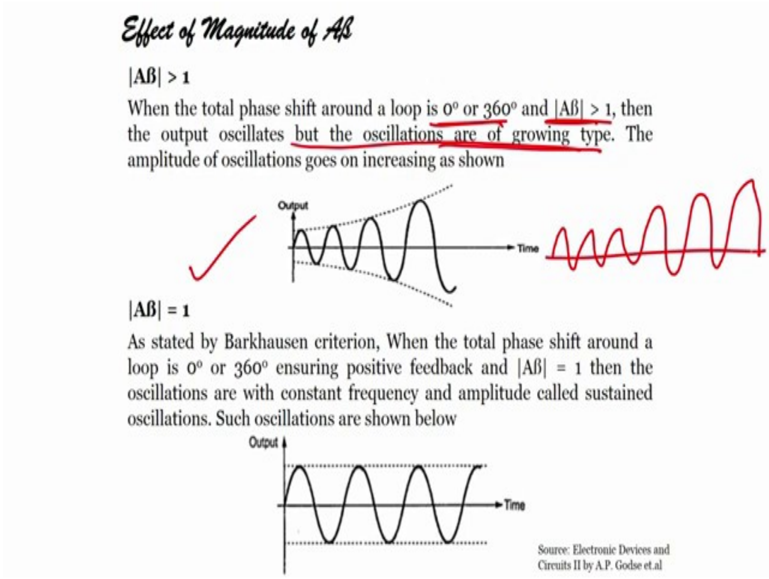
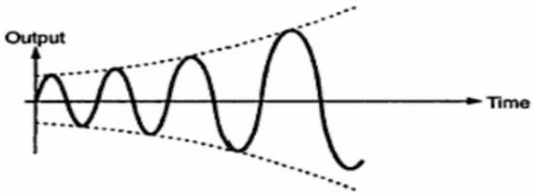


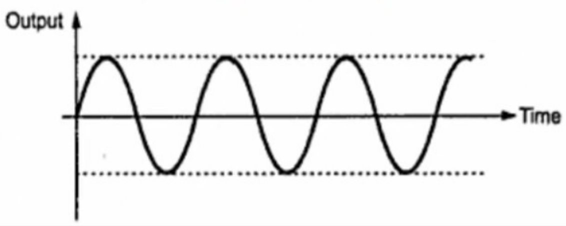
|Aß| > 1

When the total phase shift around a loop is 0° or 360° and |Aß| > 1, then the output oscillates but the oscillations are of growing type. The amplitude of oscillations goes on increasing as shown



|Aß| = 1

As stated by Barkhausen criterion, When the total phase shift around a loop is 0° or 360° ensuring positive feedback and |Aß| = 1 then the oscillations are with constant frequency and amplitude called sustained oscillations. Such oscillations are shown below



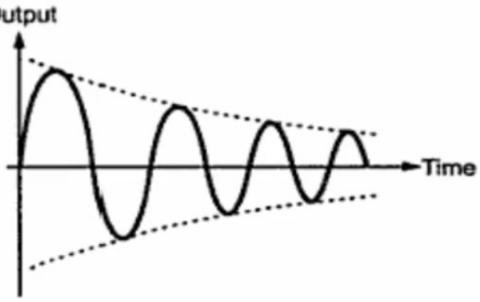
Source: Electronic Devices and Circuits II by A.P. Godse et.al

|Aß| < 1

When the total phase shift around a loop is 0° or 360° but |Aß| < 1, then the oscillations are of decaying type i.e. such oscillation amplitude decreases exponentially and the oscillations finally cease. Thus, circuit works as an amplifier without oscillations. The decaying oscillations are shown below

So to start the oscillations without input, |Aß| is kept higher than unity and then circuit adjusts itself to get |Aß| = 1 to result sustained oscillations

The obvious question is if no input is required, how oscillator starts? And where does the starting voltage come from?



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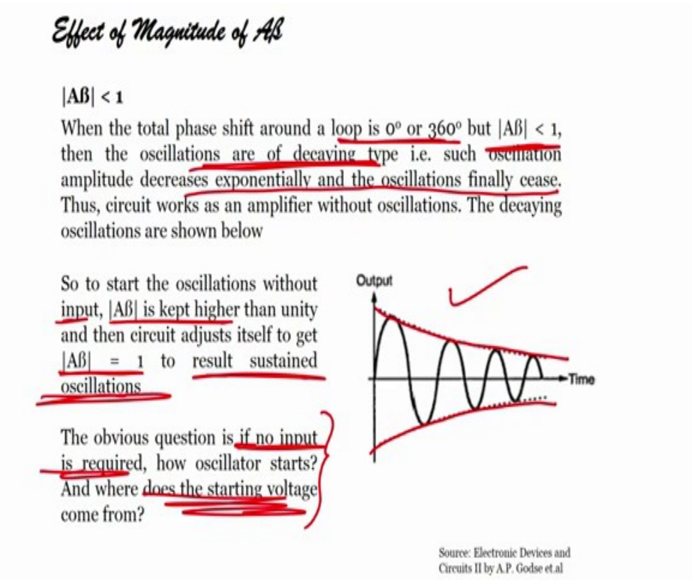

Guys you know now know why we require A β equals to 1. The obvious question here is the obvious question here is that if no input is required if no input is required, how will oscillations start? How we can have oscillations all right and when does from where does the starting voltage come from? There are two questions right, how they are not applying any input how oscillations can start and if there is a starting voltage from where it is coming from where the starting voltage is coming. So, these two signals we must understand how the how the oscillation starts and from where the signal is from the where the voltage is coming.

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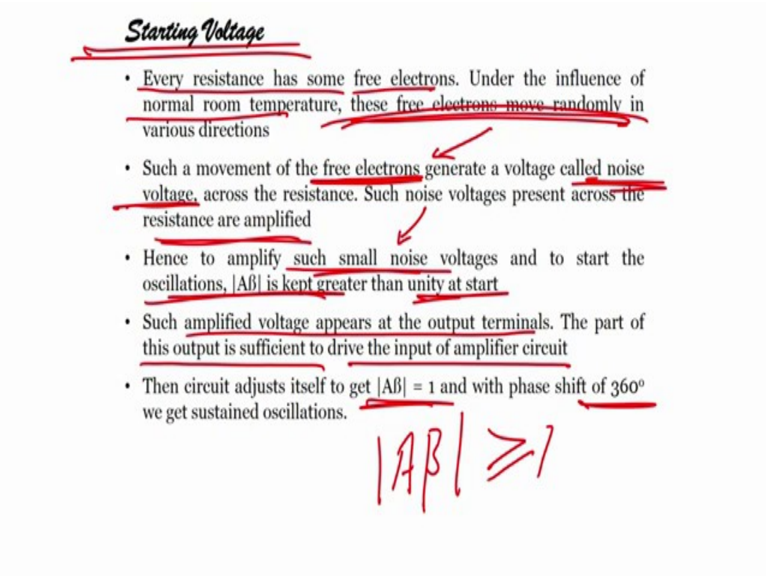

So, the starting voltage the starting voltage of the oscillator, so every resistance you see the resistance in the oscillator circuit, every resistance has some free electrons. Under the influence of normal room temperature, these free electrons move randomly in a various direction right. Such a moment of the free electrons generates a voltage called noise voltage all right. What is it that every resistance has some free electrons now, in room temperature? So, now, you have to understand the semiconductor devices and physics of semiconductor devices to understand that how the free electrons are there, how the three holes are there, in the in the room temperature how the moment occurs, but let us assume that we know how does these things happen.

And thus, we are assuming that there are free electrons. And this free electron will start moving randomly all right that how they will move randomly in the because effect of room temperature. But there are few electrons that will start moving randomly. This free movement of this electron will cause a noise; this will cause a noise across the resistance. Such noise voltages present across the resistance are amplified right. Resistance has free electrons, free electrons move at the room temperature that causes a noise voltage, this noise voltage presence across the resistance are amplified, because we have oscillator circuit.

If you come back to the screen what we see is that when this voltage is present across the resistance are amplified, hence to amplify such small noise voltages we have to keep A β greater than 1 slightly greater than 1 right to start to start what to start the amplification. Amplification of what amplification of small noise voltage, small noise voltage generates from where, some more noise voltage generates from the free electrons right that are present in the resistance, and that are moving randomly in various direction in normal room temperature easy.

Now, once we start the amplification such amplifier voltage appears at the output terminals, a part of output is sufficient to drive the input of the amplifier circuit, then the circuit adjusted itself to equal to 1, and phase shift is 360 degree or 0 degree. So, we can get sustained oscillations all right. So, this is how the starting voltage is there in the starting voltage is there when we have to use an oscillator circuit, when we have to use an oscillator circuit.

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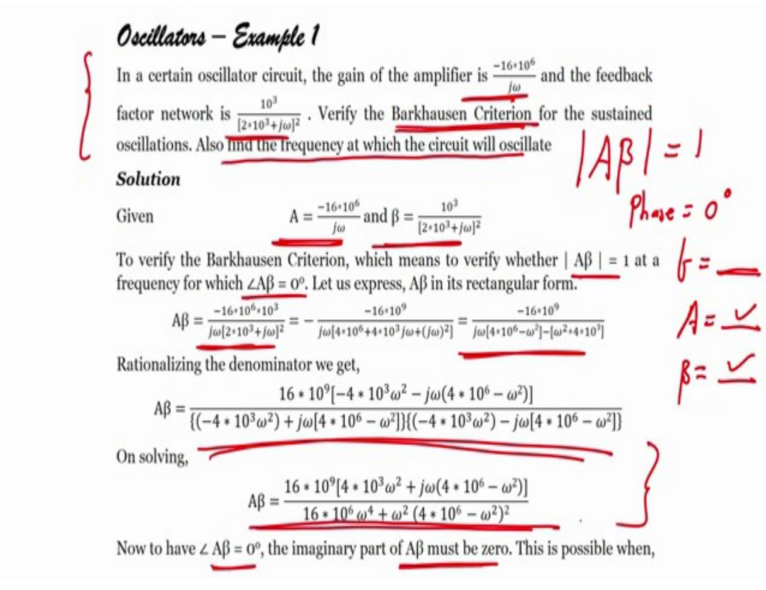

So, let us see example. Let us see an example ok, interesting. So, the problem is the problem is let us read the statement. In a certain oscillator circuit, the gain is given and the feedback is given, verify Barkhausen criterion for sustained oscillation. Also find the frequency at which the circuit will oscillate. So, what is our criterion A into β should be equal to 1. Second is phase shift phase should be 0-degree phase of the input provided through the feedback right. Third would be we required to find frequency at which the oscillations will start, this we are asked. What we are given we are given gain is given and then β is given correct. So, A is given, β is given to verify Barkhausen criteria which means we must verify A β equal to 1 at a frequency for which phase shift 0 degree.

So, let us express A β in rectangular form when we have to express in rectangular form I will write A into β is this value. If I further work on this equation, what will I get I will get this value. Now, if I recognize the denominator if I recognize the denominator. So, again guys you see you had to understand mathematics these are this is very basic mathematics very basic mathematics. So, I am presuming that you it is presumed that you know these things all right.

So, A*β is this we have this equation I had to rationalize the denominator and so we have this equation is it. And solving this equation what will I have A*β equals to this equation right. Now, A*β=0 degree right that is a criterion so, imaginary part of A*β must be 0. So, which is the imaginary part, which is the imaginary part in this equation, we must see and make it 0. This is possible this is possible when we have omega into this value equals to 0.

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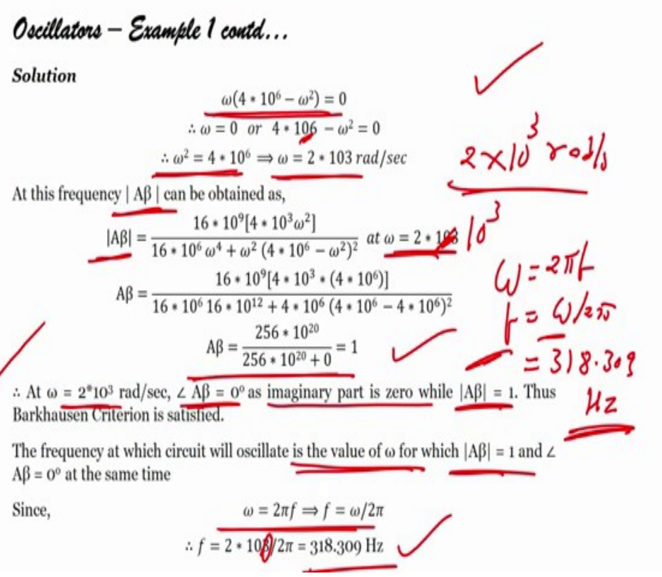

You see here where the imaginary part is. This part you see imaginary part. At this frequency, A β can be obtained as A into β, we will multiply at this value which is 10^3, then we will have A β equal to 1. When we solve this equation what we will find A β equals to 1 right that is what we want that is what we want.

At omega equal to $2*10^3$ we have; Aβ=0 degree as imaginary part is 0; while Aβ=1 thus the Barkhausen criterion is satisfied correct, because A β is 0 degree, and the A into β is 1. So, if a phase is 0, and the mode of A into β is 1 that is how we have solved the problem; So, now, we know that yes this satisfied three Barkhausen criterion, but we are asked to also find the frequency at which the oscillations will start is not it?

So, let us find the frequency all right. So, if you see the screen what we see that the frequency at which the circuit will oscillate is a value of omega for which Aβ=1, and phase shift is 0 at the same time. Since omega equals to 2 π f or f=w/2π we know the value of w we know the value of w, w is 10^3 by 2π or 318.309 hertz 318.309 hertz right yeah this is my mistake. So, just consider this 10^3, 10^3. So, it is very easy right.

Omega we already know omega is 2πf or f equals to w/2π. We already know what omega is. w is $2*10^3$, into 10 radian per second. So, we substitute the value, and we get value of f equals to 318.309 hertz which is the starting frequency for the oscillators. So, we have found out that this satisfies Barkhausen criterion, and we have found at the value of frequency two things we have found out right.

So, what we have seen guys in this particular module, we have seen how the oscillator works right, what exactly is an oscillator, what are the minimum requirements for a circuit two become an oscillator there is a Barkhausen criterion. And then we have seen that if we have A*β greater than 1, what will happen right; if it is equal to 1, what will happen; if it is less than 1, what will happen. And we have also solved a problem to understand or verify whether the problem the given set of values the problem satisfies the Barkhausen criterion or not right.

Now, what we will see in the next module, we will see that what how we can classify the oscillators right classify the oscillators. Until now, what we have seen is what are the oscillators and what are the criteria for the oscillator. Next module, we will see the classifications of the oscillator and we will go on from that point. Till then you again see whatever is taught in this module right and I will catch you in the next module till then you take care. Bye.