Phase-Locked Loops
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Lecture – 4
Simple Implementation of a Phase Locked Loop

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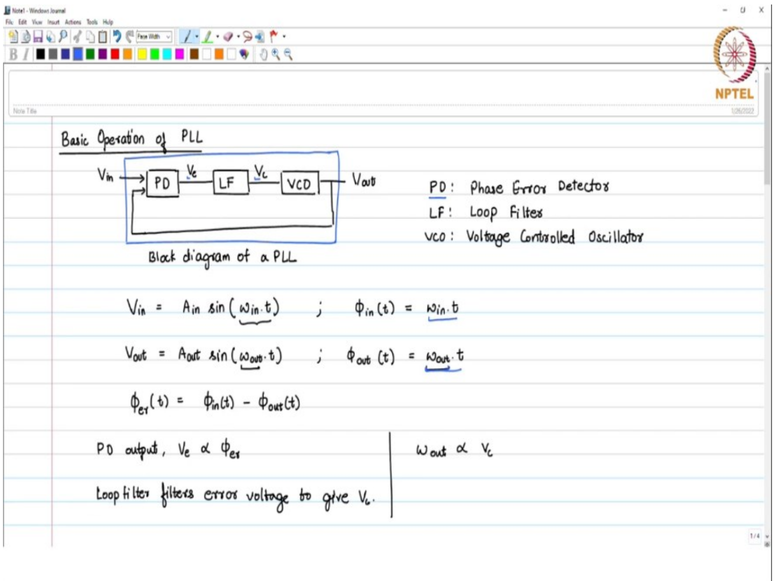

After knowing that a PLL block actually maintains a relationship between the input and the output frequency and the input and the output phase, what we would like to learn is how we can implement this PLL block. We will start with this in a very simple manner. Let us not complicate the implementation. To begin with this, we will start with a very simple example.

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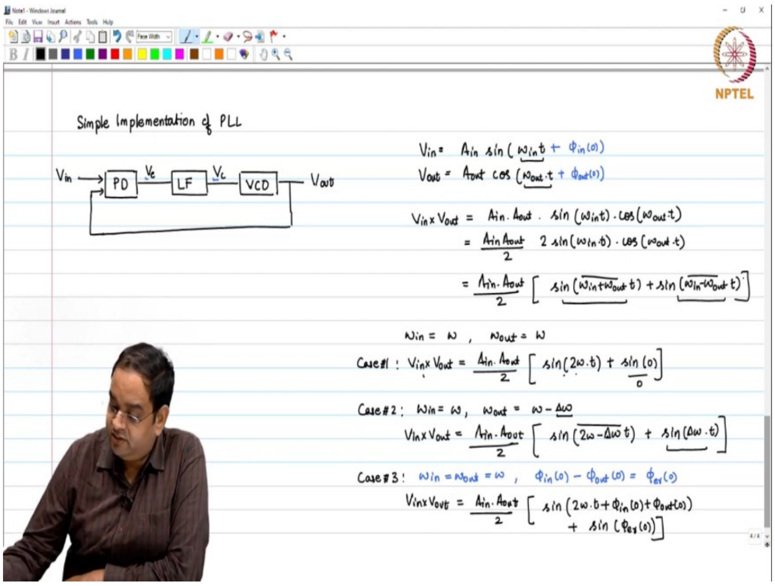

So, the thing which we are going to learn is a Simple Implementation of PLL Block. So, this PLL block is shown here. So, we know that the input and output are sinusoidal signals. We need to somehow find the phase error between the input and output sinusoidal signals.

So, let us look at it.

$$V_{in} = A_{in} \sin(\omega_{in} t)$$
$$V_{out} = A_{out} \cos(\omega_{out} t)$$

If you recall the basic trigonometric identities and you would like to know that how can I subtract one argument of the sin wave from the other, you will find that you need to multiply these two signals. So, earlier I took $A_{out} \sin(\omega_{out} t)$. You can take sin or cosine. If you take cosine, you may recall your trigonometric identity in much easier, so I will just use that. There is no problem in using sin in both the cases. So, when I multiply V_{in} and V_{out}, what do I get?

$$V_{in} \times V_{out} = A_{in}\, A_{out} \sin(\omega_{in} t) \cos(\omega_{out} t)$$

So, I am just multiplying and dividing by 2 and this I can write as follows:

$$V_{in} \times V_{out} = \frac{A_{in} A_{out}}{2} 2 \sin(\omega_{in} t) \cos(\omega_{out} t)$$

$$V_{in} \times V_{out} = \frac{A_{in} A_{out}}{2} [\sin((\omega_{in} + \omega_{out})t) + \sin((\omega_{in} - \omega_{out})t)]$$

So, if you multiply V_{in} and V_{out}, you get these particular terms. Here, you see there are two terms, one is $\omega_{in} + \omega_{out}$, and the other is $\omega_{in} - \omega_{out}$. Hence, so far, we are just able to do addition and subtraction in phase with phase variables. We have not done anything more than that.

So, this is in general what we have seen. We will see the following three cases here.
Case #1: $\omega_{in} = \omega$, and $\omega_{out} = \omega$

$$V_{in} \times V_{out} = \frac{A_{in} A_{out}}{2} [\sin(2\omega t) + \sin(0)]$$

So, if the two frequencies are same, then you will see that there are two components at the output of this multiplier or multiplication $V_{in} \times V_{out}$. One component is at 2ω and the other term is 0 itself. So, this is what you have.

Case #2: If you have a frequency error between the input and the output signals such that $\omega_{in} = \omega$, and $\omega_{out} = \omega - \Delta\omega$

$$V_{in} \times V_{out} = \frac{A_{in}A_{out}}{2}[\sin((2\omega - \Delta\omega)t) + \sin(\Delta\omega t)]$$

This is interesting. If there is a frequency error between the input and the output signal and that frequency error is $\Delta\omega$, then you get two components, and one of these components is proportional to the frequency error.

Case #3: If you have a phase error between the input and the output signals such that $\omega_{in} = \omega_{out} = \omega$, and $\varphi_{in}(0) - \varphi_{out}(0) = \varphi_{er}(0)$

$$V_{in} \times V_{out} = \frac{A_{in}A_{out}}{2}[\sin\big(2\omega t + \varphi_{in}(0) + \varphi_{out}(0)\big) + \sin\big(\varphi_{er}(0)\big)]$$

To begin with, there were two sine waves shifted by some phase. So, you have some phase offset here. In that case, if I assume that $\omega_{in} = \omega_{out} = \omega$, but $\varphi_{in}(0) - \varphi_{out}(0) = \varphi_{er}(0)$. In this particular case,

$$V_{in} \times V_{out} = \frac{A_{in}A_{out}}{2}[\sin\big(2\omega t + \varphi_{in}(0) + \varphi_{out}(0)\big) + \sin\big(\varphi_{er}(0)\big)]$$

So, you see three cases here. The basic idea was to somehow operate on the argument of the sine waves, because the actual signals which are present there are voltage waveforms; I had to operate only on the sine wave, on the phase part of the sine waves. So, we saw three cases, when you do not have frequency error, when you have frequency error, and when you do not have frequency error but you have phase error. Then you have two components, one component which is sitting at 2ω and the other component which is $\varphi_{er}(0)$, which does not vary with time.

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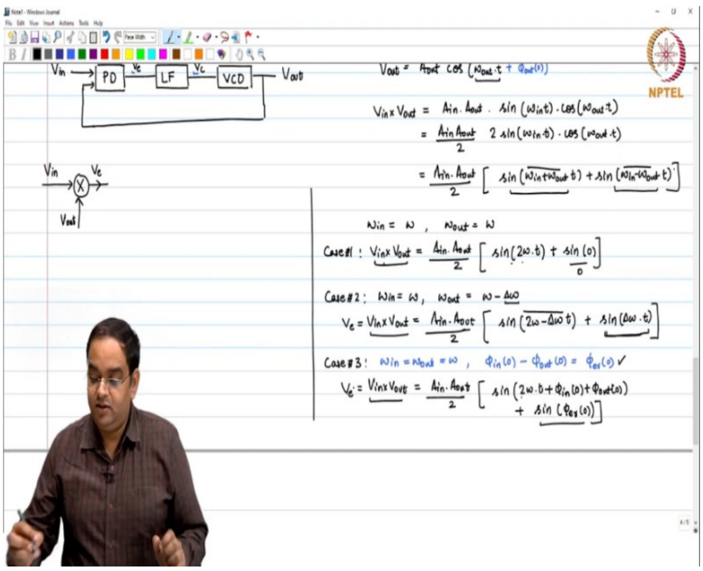

So, from here, we can say that this kind of operation between the input and the output signal gives us voltage, it is a multiplication here, so we are still getting a voltage waveform here. We get voltage which is proportional to the phase or frequency error. I am using the term proportional here because this is coming as $\sin(\Delta\omega t)$ or $\sin(\varphi_{er}(0))$. It is not directly equal to the phase or frequency error but it is proportional, this proportionality is non-linear here, because it is sin.

So, I will just replace this PD block using a simple mixer which is shown by a cross sign here. I am feeding V_{in} and V_{out} and the output of this mixer is the error voltage. So, if you have a mixer and you multiply these two voltages in any circuit, you will see that the output is also a voltage. So, I get error voltage (V_e) here. So, this V_e voltage is proportional to the phase and frequency error.

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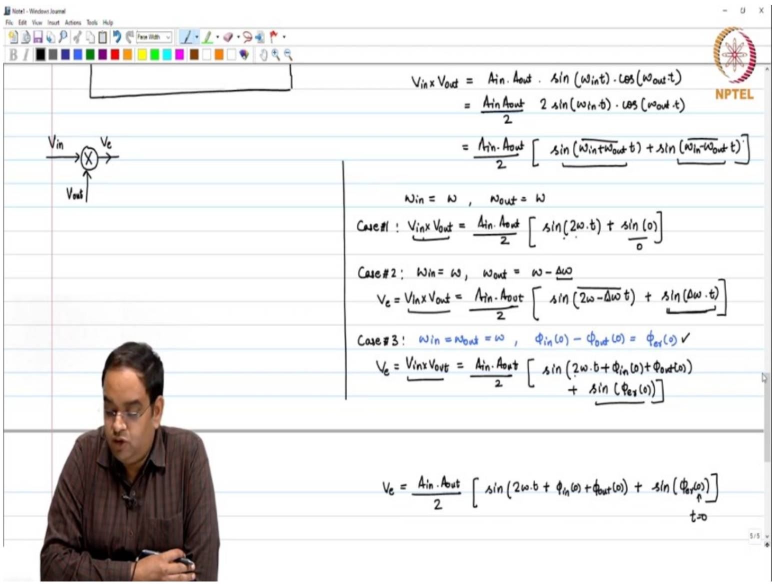

Now, let us just try to take the simplest case, which is case #3. In case #3, we have,

$$V_e = \frac{A_{in}A_{out}}{2}\left[\sin\big(2\omega t + \varphi_{in}(0) + \varphi_{out}(0)\big) + \sin\big(\varphi_{er}(0)\big)\right]$$

Here 0 refers to the time instant t = 0. So, now, if that is the case where our error voltage has two terms, $2\omega t$ and the phase error between the two signals, one is the input, other is the output. What will the PLL block do if the frequencies are same? It will try to actually make the phase error 0.

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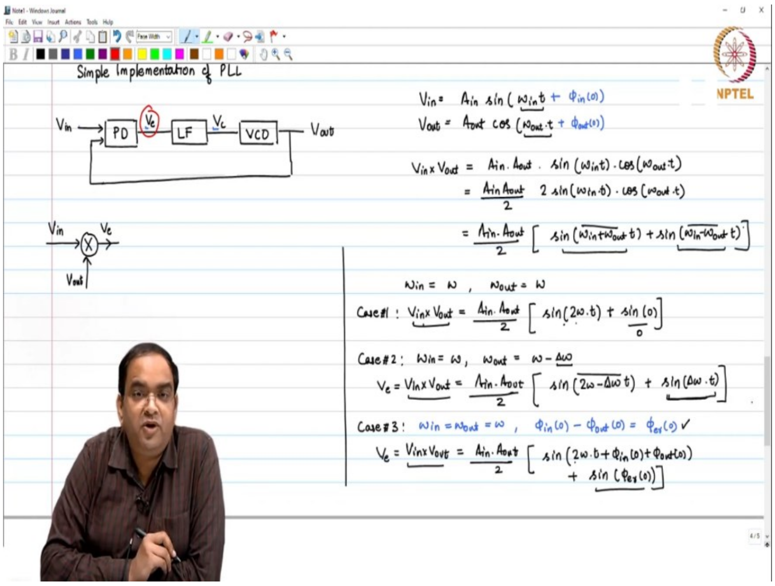

So, what do we need to process in this particular PLL block? We got two components at V_e output, one component at 2ω frequency and the other component at dc.

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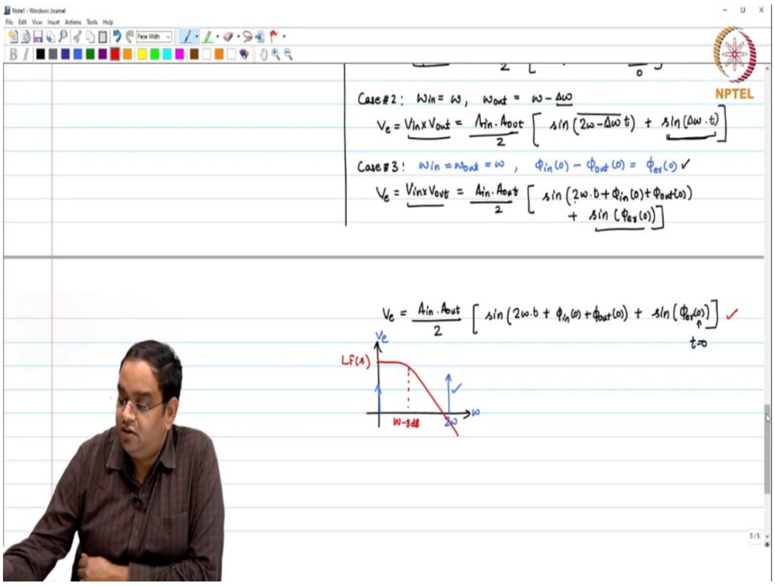

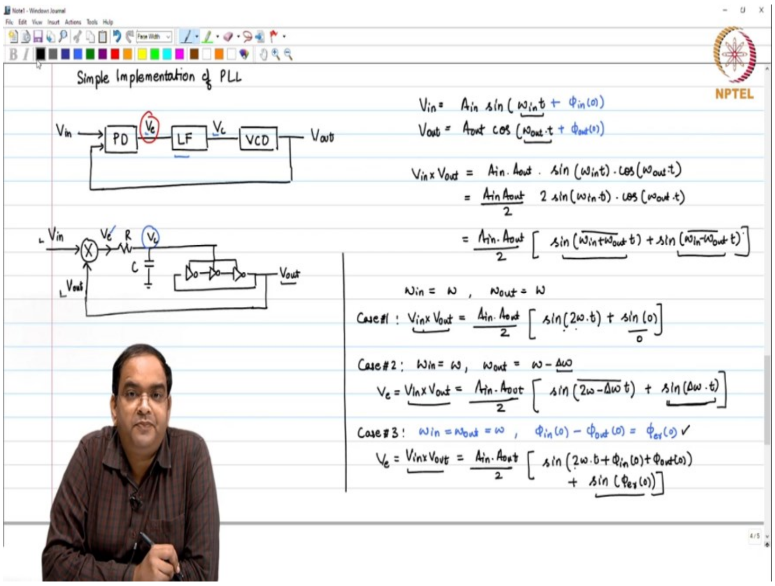

So, if I just look at the frequency spectrum of this V_e signal, there are two components, one component at 2ω, other component at dc and I need to operate on the phase error. If I need to operate on the phase error, that means I have to reject this 2ω component. So, if I have to reject the 2ω component, the loop filter is going to help us do so. So, the loop filter will help us in rejecting the 2ω component. What did we see earlier? The loop filter is a block whose input is a voltage, output is a voltage, so it is an easy one, so, loop filter is a block in general with transfer function something like this. This is your loop filter transfer function. It will have some bandwidth ω_{-3dB}, and this bandwidth is going to be smaller than the 2ω component for sure.

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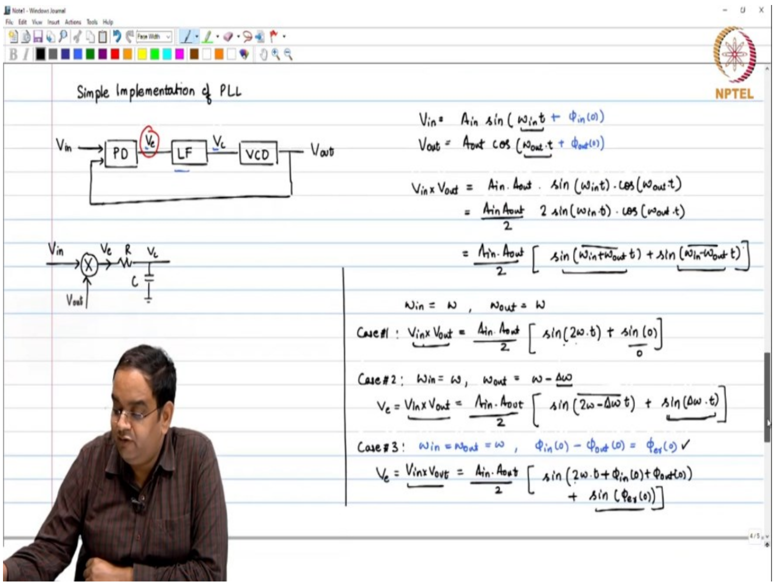

So, a simple substitution for the loop filter is a simple RC filter here. So, this particular RC filter, as you see, is going to filter the 2ω component and give you the control voltage.

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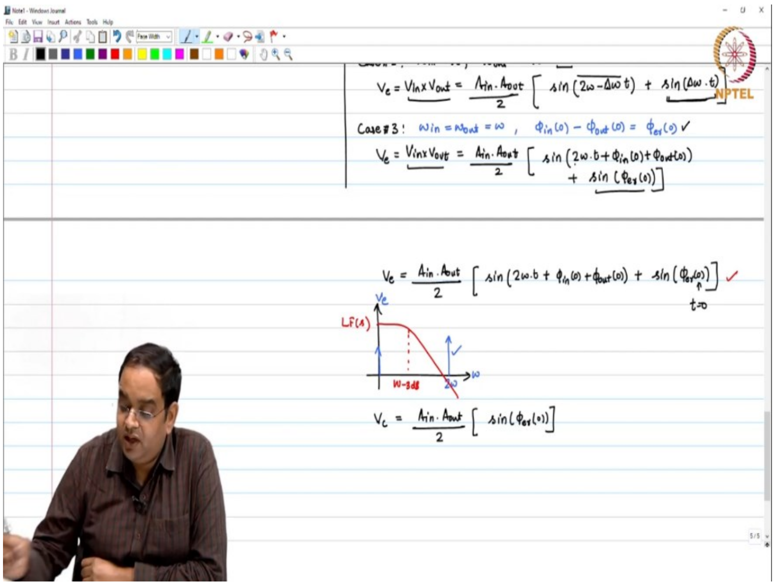

So, from this, if I filter the 2ω component, the control voltage will be given by,

$$V_c = \frac{A_{in}A_{out}}{2}\left[\sin\left(\varphi_{er}(0)\right)\right]$$

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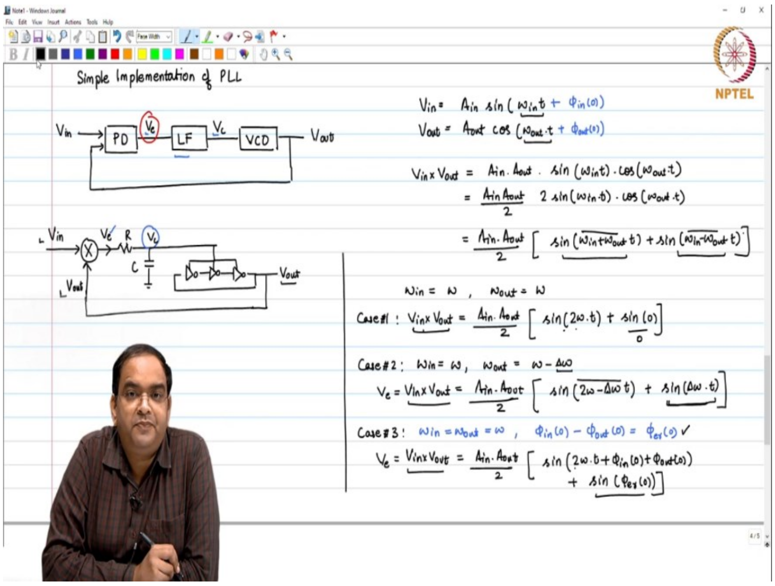

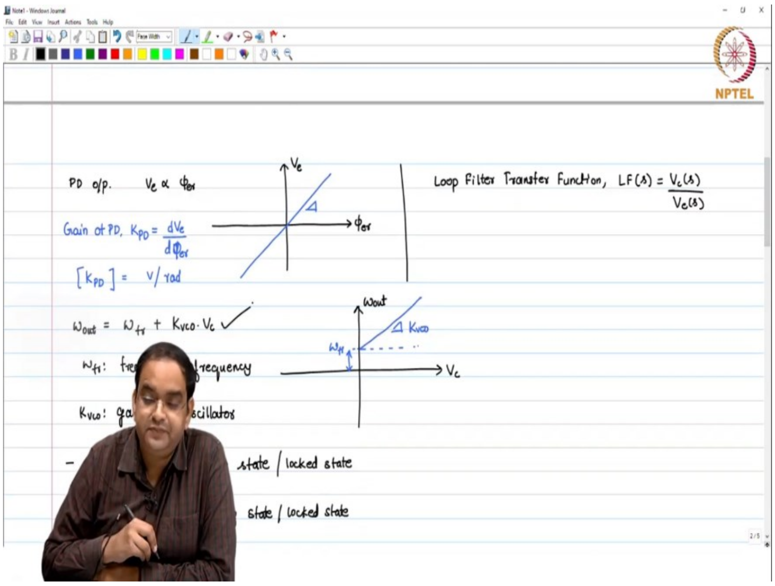

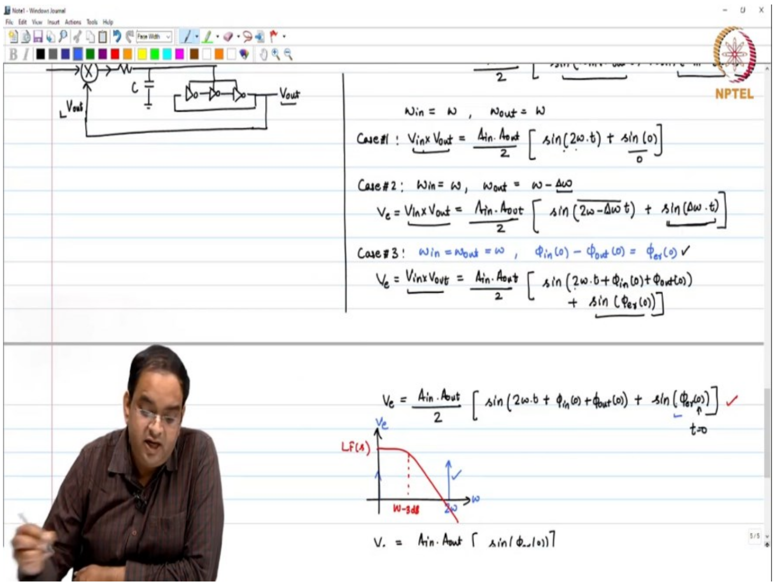

Now, this is our control voltage and this control voltage is going to change the frequency of the oscillator. For now, we will not go into the block behind the oscillator. So, I will just draw one block using inverters which is commonly used as a voltage controlled oscillator. There is no need to understand right now how it is operating, we will go into the detail of these blocks in some time. So, this is a block which has an output voltage V_{out} and this V_{out} is related to V_c using the frequency relationship which we talked about earlier. So, that is how you control this V_{out}. For the feedback, I will connect it in this manner.

So, what you see now is that the input is a voltage and the output is also a voltage. But I operate on the phase error between the input and the output signal and I give you error voltage like this. Then, you have the resistor R and capacitor C which constitute the loop filter. So, once you have the loop filter, you reject the high frequency component from the loop filter. Then, you have a voltage controlled oscillator which converts this control voltage to output frequency. Since the phase and frequency are related, you change the output phase. So, that is what we see as a very simple implementation of our PLL block diagram.