Microwave Theory and Techniques
Prof. Girish Kumar
Department of Electrical Engineering
Indian Institute of Technology, Bombay

Module - 08
Lecture - 39
Microwave Tubes - II: Linear Beam Tubes- Reflex Klystron and TWT

Hello. In the last lecture, we discussed conventional tubes and their high frequency limitations. After that we discussed about linear beam tubes and their basic working; followed by detailed analysis of two-cavity klystron, its working its applications and the specifications of practically available two-cavity klystrons. Today, I will discuss Reflex Klystron and Travelling Wave Tubes.

So, let us begin with reflex klystron.

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It is a low power microwave oscillator. And to design a oscillator, the first thing which we need to know is how oscillations are generated. The answer to this question is that we need to give positive feedback from output to input such that the loop gain is unity or we can say for a klystron if a fraction of output power is feedback to the input cavity such that the loop gain magnitude is 1 and the feedback path phase shift is 2 pi or multiple of 2 pi, then the klystron will oscillate.

Now, the next question is, can we make oscillator using two-cavity klystron? The answer to this question is yes, we can, but it will have some disadvantages. Such as if the oscillation frequency changes then we need to re adjust the resonant frequencies of the two cavities and the feedback path phase shift to give positive feedback. This disadvantage of two-cavity klystron can be overcome by reflex klystron, because it has single cavity. And there is a reflector or repeller to repel the electrons back to the cavity to give feedback and the feedback path phase shift can be adjusted by varying the repeller voltage, because of this reason the two-cavity klystron oscillators are not constructed and reflex klystron oscillator are constructed.

The working of reflex klystron is somewhat similar to the working of two-cavity klystron. So, working principle of reflex klystron is velocity and current modulation. So, electron beam is injected from the cathode and that injected beam travel with a uniform velocity till the cavity. And in the cavity gap, the velocity of the electrons is modulated. And those velocity modulated electrons enter the repeller space with different velocities and because of the velocity modulation and repulsive forces from the repeller plate the bunching takes place in the return journey of the electron to the cavity. Because of the bunch formation there will be current modulation in the cavity. So, this is how the reflex klystron works.

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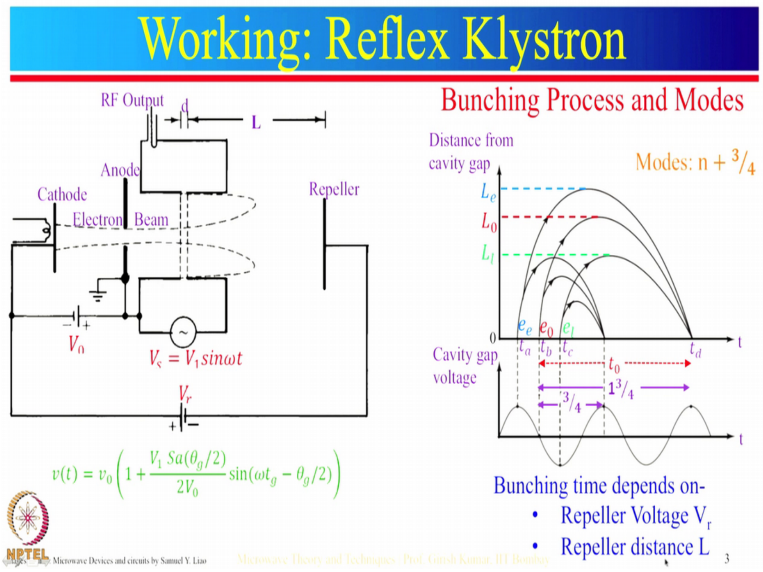

So, let us see its working in more detail now. So, this is the basic schematic of a reflex klystron. In this we have a cathode. So, this is the cathode from where the electron beam is injected. Then this is the focusing anode or accelerating anode, which focuses the electron beam or narrow downs the electron beam. Then we have the cavity, so this is the cavity which acts as buncher cavity for forward moving electrons, and catcher cavity for returning electrons or backward moving electrons.

So, this is the cavity gap where velocity and current modulation takes place and the gap is equal to d. Then we have this repeller plate which is at the potential minus v r; and this v r is very very high. So, because of this negative potential at repeller plate, the electron beam coming from this cavity gap is reflected back to the cavity. So, this is the basic structure of a reflex klystron.

Now, what is the difference in the structures of two-cavity klystron and reflex klystron? The first difference is that and two-cavity klystron there are two cavities, whereas in reflex klystron there is only one cavity which access both buncher cavity and catcher cavity. And the another difference is that in two-cavity klystron at this place there is a collector which is used to collect the electron beam coming from the output cavity; whereas in reflex klystron there is repeller plate in place of the collector which is used to repel the electron beam.

Now the question is why we need this repelling of electron beam? The answer to this question is that for electrical oscillations we need feedback from output to input and that feedback is produced by this repeller plate by reflecting the electron beam back to the input cavity. So, these are the differences in the structures of two-cavity klystron and reflex klystron.

Now, let us see how electron move in reflex klystron tube. So, electron beam is generated from this cathode which moves with a uniform velocity till this cavity and in this cavity the velocity modulation takes place. So, some electron will be accelerated and some electrons will be the decelerated. And there will be no effect for some electrons. So, the electrons which enter this cavity at positive gap voltages will be accelerated. And those electrons will have greater velocities. And the electrons which entered this cavity when the gap voltage is negative, those electrons will be decelerated and their velocities will be lesser as compared to the other electrons. And the electrons which enter this cavity when the gap voltage is 0, their velocity will not be changed by this gap voltage. So, all these electrons will have different velocities as they enter in the repeller space. This is the repeller space.

Now, since these electrons have different velocities in this repeller space, so they will travel different distances in the repeller space depending upon the velocities. The electrons which has greater velocities will go deeper in this repeller space and travel more distance, whereas the electrons which has lesser velocities will travel less distance in the repeller space. So, after entering into the repeller space, they feel repulsive force from this repeller plate because of the high negative potential at this repeller plate.

And as they go closer to the repeller plate, the repulsive force increases. And at some point the repulsive force will make their velocity 0 and reflect those electrons back to the input cavity. So, because of this velocity modulation and repulsive force from this repeller plate, the bunching of electrons will take place in the return journey of the electrons.

And one more thing we want that the bunching of electrons should take place at the centre of this gap cavity gap. And the timing of this bunching should be such that the phase of gap voltage should be retarding. This is done to ensure the maximum power transfer from electrons to the cavity. So, because of this power transfer there will be oscillations. So, this is how oscillations are sustained in the reflex klystron by to and fro movement of electrons from cavity to repeller space. So, this is how electrons move in this reflex klystron tube.

Now, let us see bunching process and the modes and reflex klystron, this vertical axis represent the distance from the cavity gap towards the repeller plate, and this horizontal axis represent the time taken by the electrons in moving in the repeller space. These curves represent the path of movement of electrons in repeller space. So, different electrons follow different paths depending upon their velocities while they enter the repeller space. So, this is the cavity gap voltage varying with time.

Now, to understand the bunching process let us say we have an electron reference electron V naught, which reaches the cavity gap at this point of time. And at this point of time, the cavity gap voltage is 0. So, the velocity of this electron will not be modulated by the cavity gap voltage. So, this electron will enter in the repeller space with the same velocity with which it entered in the cavity gap. After entering into repeller space, this electron will feel repulsive force from the repeller; and because of that force the velocity of this electron will decrease as you can see from this path.

So, this vertical axis is distance, this is time. So, the velocity will be distance divided by time that is the slope of this curve. So, as the electrons move closer to the repeller plate, the slope of this curve decreases. It means the velocity of this electron decreases as it moves closer to the repeller plate. And at some point let us say L naught after travelling this, L naught distance the electron velocity will be 0, and it will be reflected back towards the cavity. And after this point, it will start moving towards the input cavity in this path.

So, let us say this electron takes t naught time in the to and fro journey of cavity gap to this distance L naught in the repeller space. Now, let us say we have one more electron that is early electron e e which reaches the cavity gap when the gap voltage is positive. So, this electron would be accelerated by this gap voltage, and its velocity will be maximum. So, this early electron will enter the repeller space with maximum velocity. So, it will travel maximum distance in the repeller space.

So, let us say that distance is this L e. After this distance L e, this early electron is also reflected back towards the cavity. And this will take more time as compared to the reference electron, and that time is equal to this time t naught plus this time. So, this time is t by 4, one-fourth of the time period of cavity gap voltage. So, time taken by early electron in the journey of cavity gap to this length L e and back to the cavity gap will be the time taken by the early electron plus one-fourth of the time period of cavity gap voltage. Now, let us see we have one more electron that is late electron which reaches the cavity gap when the gap voltage is negative. So, because of this negative gap voltage, this electron will be decelerated and its velocity will be minimum.

And because of this minimum velocity, this electron will travel lesser distance in the repeller space as compared to the reference electron as well as the early electrons. And, let us say it travels this L l distance and to cover this distance let us say it take t d minus t c time which is equal to the time taken by the reference electron t naught minus one-fourth of the time period of the cavity gap voltage. So, this is how the bunching of electrons takes place after the time t naught with respect to reference electron. So, this bunching takes place at the cavity gap as you can see from this graph. So, this vertical axis is distance and this represents the zero line that is the zero distance from the cavity that is the cavity itself.

So, bunching takes place at the cavity gap itself. And as I discussed earlier the time of this bunching should be such that the bunching encounter the retarding phase of the gap voltage this is the half cycle of retarding phase, this is also retarding phase half cycle. So, bunching should occur either in this cycle or in this half cycle. Now, depending upon the bunching cycle, there are different modes and reflex klystron. So, if bunching takes place in this cycle, then it is called as 3 by 4 mode. And if bunching take place in this cycle, then it is called as 1 plus 3 by 4 mode.

In general depending upon the bunching cycles, there are n plus 3 by 4 mode n reflex klystron where n is the integer. Now, the question is how we can change this bunching time depending upon the requirements. Answer to this question is that the bunching time depends on two parameters which are repeller voltage V r and repeller distance L. So, by varying these two parameters we can change the bunching cycle or we can change the mode of the reflex klystron.

So, this is how by selecting the proper time and the proper place of bunching, the oscillations are sustained in the reflex klystron tube. This is all about the working of reflex klystron.

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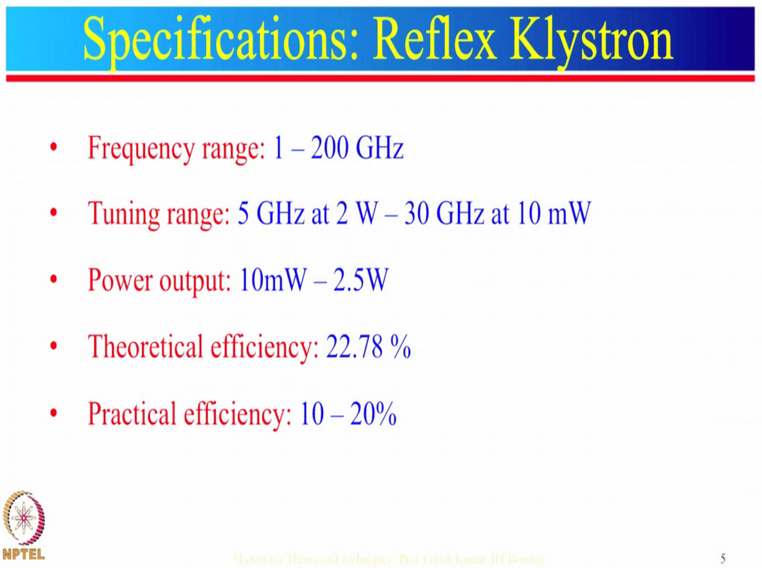

Let us move onto the specifications of practically available reflex klystron. So, the frequency range over which reflex klystron can work is roughly from 1 gigahertz to 200 gigahertz. And the tuning range is from 5 gigahertz at to watt to 30 gigahertz at 10 mili watt and the power output that can be given by a reflex klystron is from 10 mili volt to 2.5 watt. The theoretical efficiency of reflex klystron is about 20 percent, and the practical efficiency of the reflex klystron is somewhere between 10 to 20 percent.

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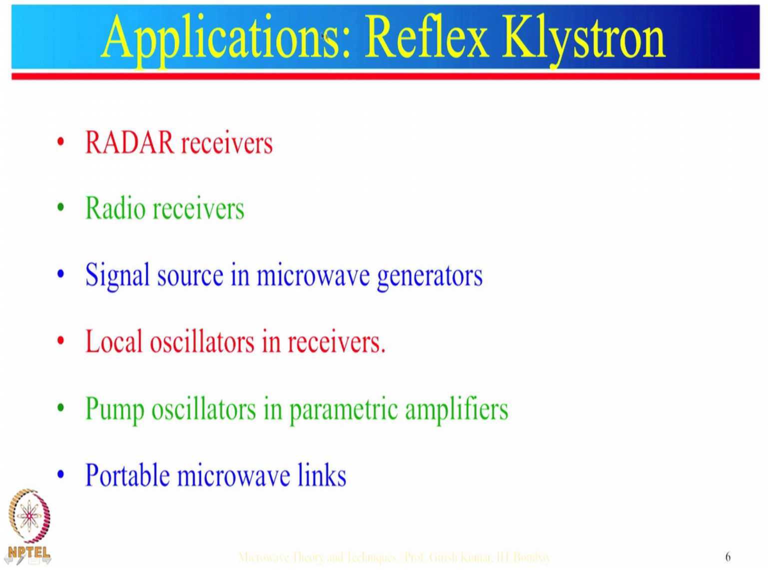

Now, let us look into the applications of the reflex klystron. There are many applications of reflex klystron such as they can be used in radar receiver. They can be used in radio receivers or in signal sources in microwave generators. They are also used in local oscillators and receivers, or in pump oscillators and in parametric amplifiers. And these are also used in portable microwave links. So, these are all applications of reflex klystron.

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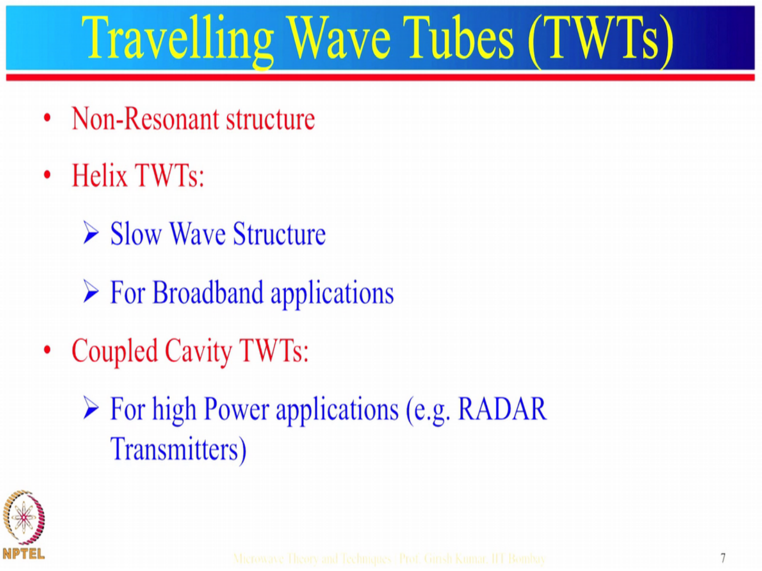

Now, let us move onto the next microwave tube which is travelling wave tube. So, these microwave tubes are non-resonant structures. And they are of two types. First one is helix travelling wave tubes which are slow wave structures and are used for broadband applications. And another one is coupled cavity travelling wave tubes which are used for high power applications such as radar transmitters. I will discuss these two structures one by one, but before looking into the helix travelling wave tube let us see what are slow wave structures.

So, slow wave structures are used to slow down the electromagnetic wave. Now, the question is why we need to slow down the electromagnetic waves. The answer to this question is that the phase velocity of electromagnetic wave is greater than velocity of light in a ordinary wave guide. And the electron beam can be accelerated up to a selection of velocity of light in vacuum. So, there is a huge mismatch in the velocities of these two; one is electromagnetic wave and another one is electron beam. So, because of this velocity mismatch, they will not get enough time to interact with each other.

So, there will be no energy transfer from one to another. And to increase this energy transfer, what we need to do, we need to decrease the velocity of electromagnetic wave, so that electron can get enough time to interact with the electromagnetic wave.

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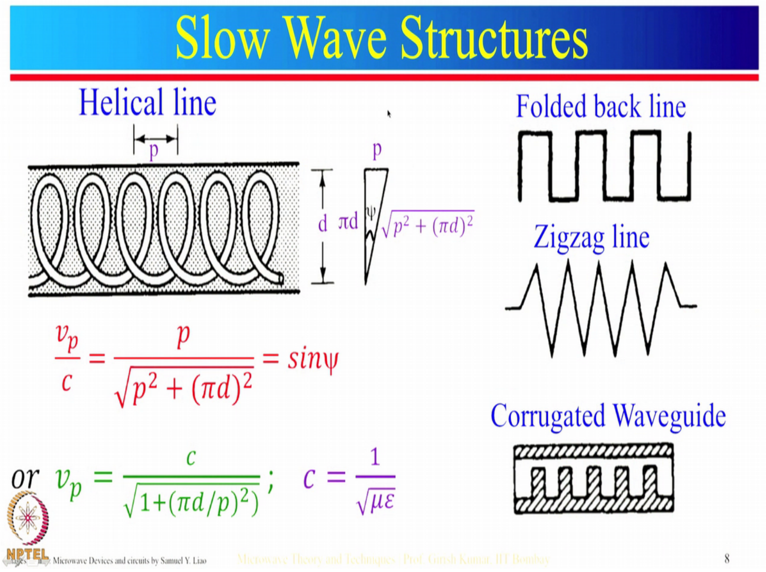

This job is done by slow wave structures. There are many slow wave structures such as helical line, folded back line, zigzag line, corrugated waveguide and so on. And what happens in these slow wave structures is that we provide a larger path length for a electromagnetic wave to travel from one point to another as compared to the electron beam path that is the shortest path.

So, to understand how velocity changes in slow wave structures let us take an example. So, if I want to move from this point to this point let us say this distance is d. So, there are multiple paths to travel from this to this point. So, one is the straight path which is the shortest path, another path can be zigzag path or this path or helical path or this path and so on. And in all these paths, the displacement is same which is d, but the time taken to travel through that path increases depending upon the path length. So, since the time is increased so velocity will decrease. And this concept is used to reduce the velocity of electromagnetic wave.

Now, let us see how velocity of electromagnetic wave is reduced and helical line slow wave structure, and what is that value of phase velocity after decreasing. Let us say the distance between two turns of the helix is p that is axial length and the diameter of the turns is d, then we can find the path length traveled by the electromagnetic wave for a axial movement of p. We can find that distance using Pythagoras theorem and that distance will be under root of p square plus pi the whole square.

Now, the ratio of phase velocity of electromagnetic wave travelling along this helix and the phase velocity of electromagnetic wave which is travelling directly in the straight path will be the reverse ratios of their path lengths. So, for electromagnetic wave which is travelling in a straight path, the path length is p and for a electromagnetic wave which is traveling through this helix path length is under root p square pi d square for axial movement of p. So, the ratio of v p divided by c will be p divided by under root of p square pi d square. By simplifying this one we can get v p phase velocity is equal to c divided by under root 1 plus pi d divided by p whole square. So, we can get this by dividing both numerator and denominator by p. This phase velocity is less than C as you can see from this equation.

So, this is how the phase velocity of electromagnetic wave is reduced from greater than velocity of light to less than velocity of light. And depending upon our requirement of phase velocity, we can change these two parameters that is d is diameter of the helix, and p is the distance between the turns. So, by varying these two parameters we can change the phase velocity of electromagnetic wave according to our requirement. So, this concept is used in slow wave structure helix travelling wave tube. Now, let us move on to the helix travelling wave tube.

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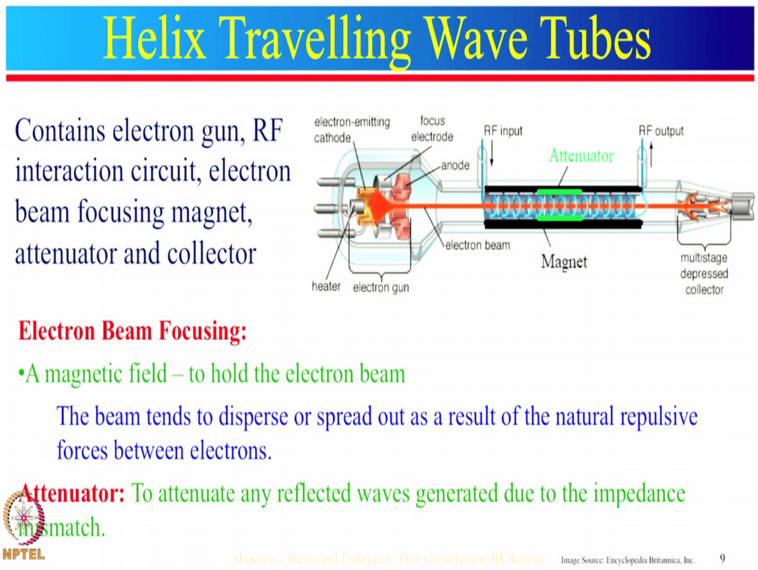

In general helix travelling wave tubes contains a electron gun and RF interaction circuit and electron beam focusing magnet and attenuator and a collector. Let us see these things one by one.

So, electron gun is used to inject electrons in the tube and input RF signal is given to this end of the helix and at the other end RF output is taken out. There is a surrounding magnetic field to hold the electron beam as they tend to spread out because of the repulsive forces present between the electrons and that magnetic field is produced by the permanent magnet present surrounding the helix. And next we have a attenuator which is used to attenuate any reflected wave generated due to the impedance mismatching. And this attenuator is placed after a sufficient length of RF interaction region, so that the attenuation of amplified RF signal is insignificant as compared to the amplification. And then we have a collector to collect the electron beam.

So, this is all about the components present in the travelling wave tubes. And the next lecture we will start from this point onward. And just to summarize what we discussed today is first we started with reflex klystron, we discussed its working principle, then the detailed analysis and detailed working of reflex klystron and its applications. Then we discussed the slow wave structures, and how they slow down the electromagnetic wave and type of slow wave structures. After that we started helix travelling wave tubes.

In the next lecture, I will start from working of helix travelling wave tubes, then I will discuss the applications and specifications of practically available helix travelling wave tubes, then the comparison of helix travelling wave tube amplifier and klystron amplifier. After that, I will discuss cross field microwave tubes such as magnetrons, their working their applications and specifications of practically available cross field tubes.

Thank you.