Basic Building Blocks of Microwave Engineering

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Lecture - 18
Microwave Tubes: Part II and Amplifiers

Of these series on basic building blocks of microwave engineering now we are continuing our discussion on microwave tubes. So, we have seen already reflex klystron the principle of velocity modulation etcetera. In this lecture, we will see another oscillating microwave tube that is magnetron the statically which was invented first.

Actually, basically this invention of magnetron by collaboration between British scientist and American scientist made the invention of radar possible and that is why in the second world war the allied forces the they could use the radar and that tilted the military balance in favor of the allied powers and so this magnetron this came out of military technology development it was the first microwave source because for radar you cannot use klystron also the principle of klystron was known at that time. But this velocity modulation was first demonstrated in the form of magnetron and magnetron can produce high power basically radars etc were operated there in our actually IIT Kharagpur nearby there is an air force base Kalaikunda. So, from there we when our department, electronics department started we got a magnetron which we also when in our student days we experimented with that. So, that used to get good amount of power in our lab we used to see magnetron there now-a-days we do not use it.

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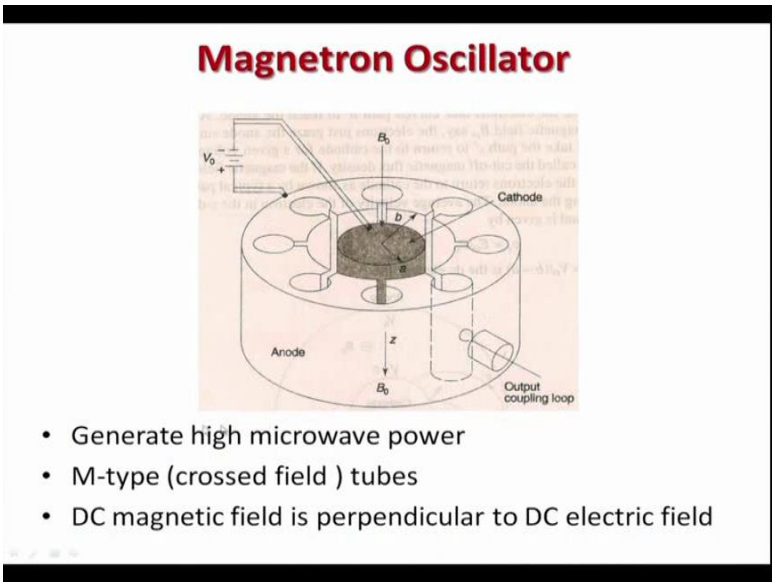

So, this magnetron oscillator it is, it can generate high micro wave power. It is an m type tube. You see the d c magnetic field here is perpendicular to the d c electric field this it is actually the, this cylindrical structure actually magnetic field is denoted by b not. So, magnetic field is here, but electric field; that means, in the axial direction magnetic field, but electric field in the transverse direction. Because cathode, this is the cathode cylindrical cathode inside and then this whole thing are anode and the interaction takes place through some slots cut regularly and this is the output coupling loop by which power is extracted. And the bias is applied; you see the negative bias is applied to the cathode the positive bias to this outer cylinder which is anode.

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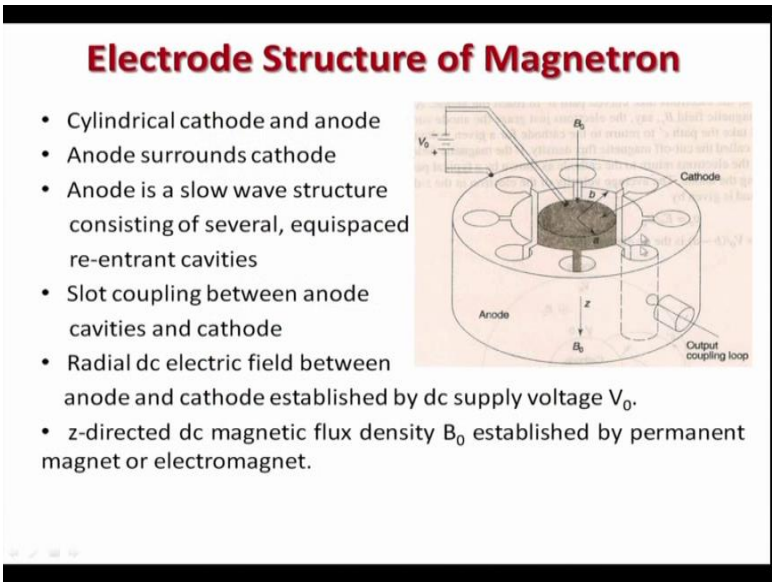

Now, cylindrical cathode both the cathode and anode they are cylinder, anode is the larger cylinder cathode is the smaller cylinder anode surrounds cathode. Anode is a slow wave structure that is why you see that there is some periodically there are several equispaced re-entrant cavities. You see there is a re-entrant cavity, but those are equispaced. So, there are many re-entrant cavities and they are equispaced if we have any wave propagation direction if we have a periodic structure that becomes a slow wave. Yesterday we have seen that normally in a web guide the waves are fast waves their phase velocity is more than the velocity of light, but if we put if we want to slow that wave we can put some periodic disturbances. So, re-entrant cavities here are disturbing and it is becoming a slow wave structure.

Now, there are slot cuts, this is a slot it cut between anode cavities and cathode. So, this anode cavities, this re-entrant cavity and cathode the you put the slot the electrons which are emitted by cathode they interact with this re-entrant cavity inside radial dc electric field between anode and cathode established by dc supply voltage v not. Radial dc electric field, the field will be radial because anode and cathode these are cylindrical structures. So, there will be radial dc electrical field and z directed dc magnetic flux density v not established by either a permanent magnet or electro magnet not shown here. But there should be a magnetron there should be the electro magnet or magnet that should be present to give that focusing thing. So, that always the magnetic field is in this direction.

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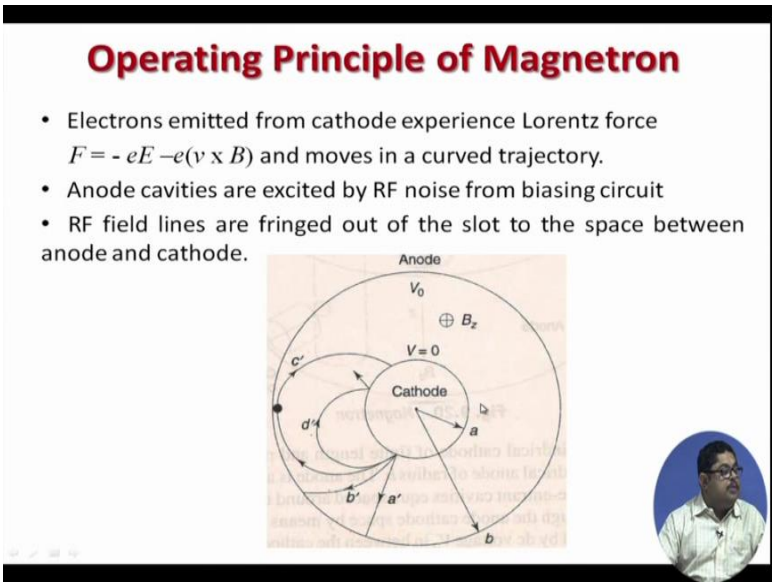

Now, operating principle you see the magnetic field is inside going into the paper and the cathode and anode their potential is this. So, electrons emitted from cathode, this is same like they will experience the Lorentz force that force we know from our basic knowledge this will be given by e into E by this and that force always makes an electron starting from here because these electrons started from cathode. So, if this v z is going there if you apply Lorentz force will make it to follow a circular trajectory. So, the electron moved in this circular trajectory, anode cavities are excited by RF noise from biasing circuit, anode is the re-entrant cavities. So, re-entrant cavities already anode is positive dc or dc supply. So, there will be RF noise then depending on the anode cavity structure there will be a resonant micro wave frequency. So, already there is an RF field present inside the anode.

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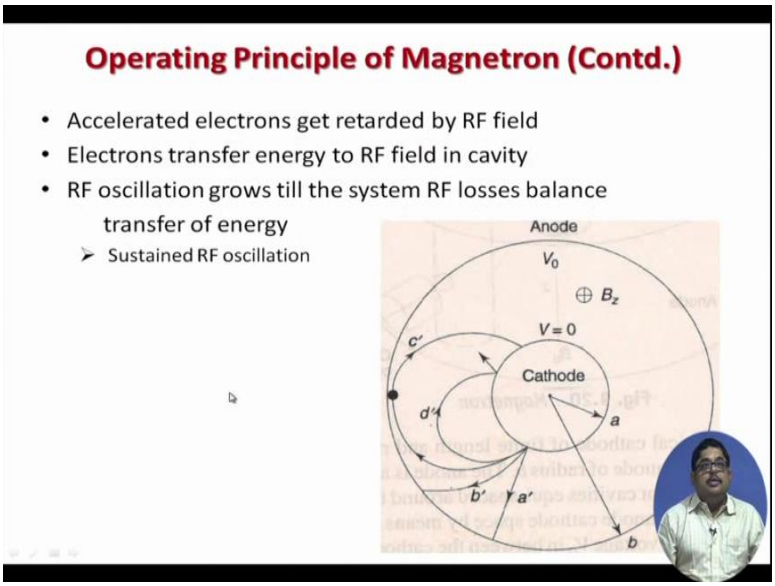

Now, this electron that will enter there and these RF field lines are fringed out of the slot. So, RF field lines are fringed out. So, RF fields come out through these slots periodically and the electron from the cathode it is going. So, it is interacting with the RF field and then it will again make that come back to the cathode. So, you see now accelerated electrons get retarded by RF field, electrons stands for energy to RF field in cavity and RF oscillation grows till the system RF losses balance transfer of energy that gives it sustained RF oscillation. So, principle is same finally, cathode collects the electrons that it has emitted then only the circuit can complete.

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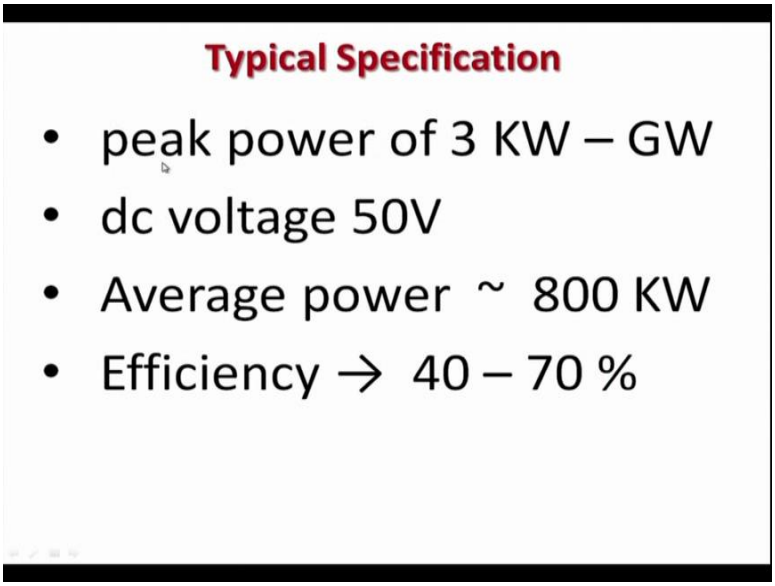

Typical specification peak power of 3 kilo watts to sub giga watt is possible, dc voltage 50-volt dc, average power it can deliver 800 kilo watts, efficiency is higher than (Refer Time: 07:37) 40 to 50 percent then what is the problem? The problem is the phase stability of the produced signal is not good. So, the produced a c signal does not have a good phase stability where as the since since in case of (Refer Time: 08:03) we have a good stability.

So, that is why if you require a stable source then people prefer this, but for high power this now-a-days people have also developed the high-power equivalent of klystron so that will be much better than this. Also, electron magnetrons are also made at higher; people are trying to make the high power of magnetrons more stable that is called relativistic magnetrons. Indian scientists are also trying to develop relativistic magnetrons etcetera. You know various depends laboratories etcetera they are trying. Now operating principle acceleration, I have already said this to be (Refer Time: 08:49).

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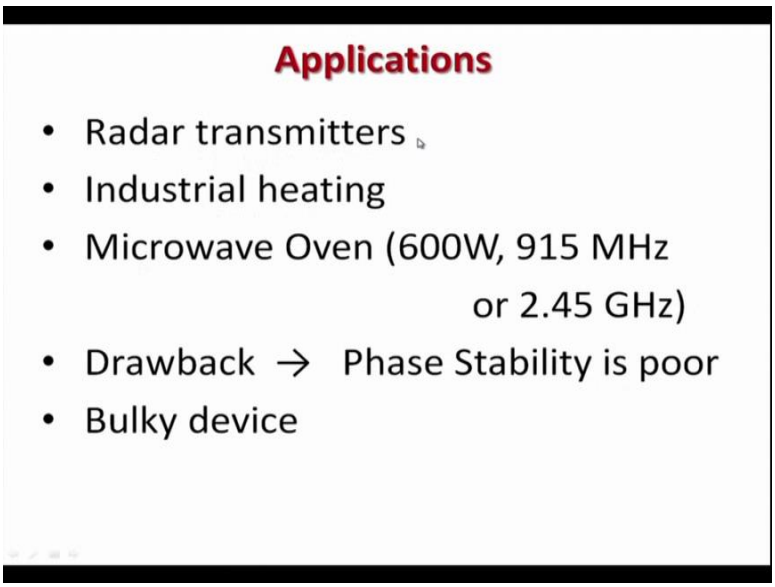

What is the application of magnetrons definitely radar transmitters particularly high and one another very also industrial heating, you know micro wave heating has got various applications in agriculture industry because various foods they have water content so that waters are natural breeding ground for various microbes. So, the spoiling of water while spoiling of food the culprit is the water. So, by industrial heating if that water can be removed then a food can be preserved for lot of time. Apart from that there are many

places where we want to industrial heating magnetron is used and in all of your houses this microwave oven.

Basically, you see in the oven or any heating application you do not require a stable source you require that the source should give power the phase between different cycles whether the oscillator is phase is not stable that does not matter there. So, microwave oven invariably have a magnetron as the source of power 600 watt is a typical output of the micro oven and it is operated 2.45 giga hertz in most of the countries because 2.45 giga hertz is the industrial scientific and medical band it is clean, you do not require license. Because otherwise 600 watts of micro power if you produce you require a license, but in this industrial or scientific band ISM band you do not require any license. So, 2.45 giga hertz is that in our country we have magnetrons in this, but in some other countries this 915 mega hertz is also ISM band there we can have micro wave oven. But most common, but most of the micro wave ovens particularly in our countries it is 2.45 giga hertz.

And obviously, it is a bulky device because you have a magnet. The moment you have a magnetic material the device is bulky. We have seen circulator that the moment you have ferrite you have bulky thing similarly magnetron is also much more bulky than it is.

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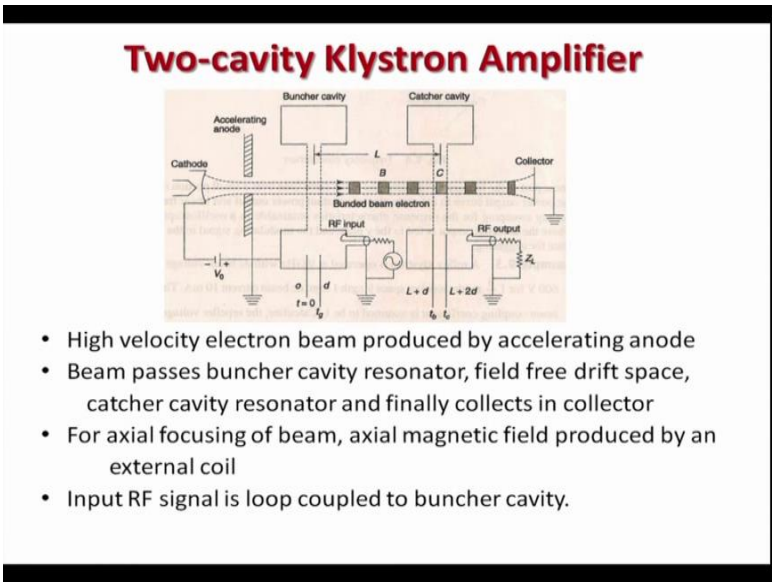

I do not have a picture of magnetron because our lab magnetron that we had now we have sold that so it is obsolete. Now let us see that some micro wave tubes can give you

can be used as amplifiers, we have now seen oscillators both reflex (Refer Time: 11:37) now the amplifier counterpart of a klystron is klystron amplifier. Simply klystron means a klystron amplifier; it is a two cavity structure not a single cavity. So, you see two intern cavity, this is 1 intern cavity this is another intern cavity. Unlike in the previous case where the two-intern cavity was horizontal here it is in this direction electron beam is like this. So, electron beam is coming then high velocity electron beam produced by accelerating anode electron beam this is an accelerating anode it is coming here it is seeing this inter action thing already. So, this is called buncher cavity, beam passes buncher cavity resonator this is cavity means it is a resonator.

And then there is a field free deep space. There is not a much field because this length is quite large. So, here almost they do not experience any field again they come to another intern cavity that is called catcher cavity. And finally, they are collected, a collector the plate for axial focusing of the beam. So, that the beam oven it is passing through such a large journey it need as to be focused otherwise some of the electrons will diverge away. So, for axial focusing of the beam an axial magnetic field is produced by an external coil that is not shown here, but there is an external magnetic field so that in this axial direction there is a field. So, both the electrical field and axial field they are in the same direction. So, it is again o type tube, but it is not a tube it is an amplifier input RF signal is loop coupled to buncher cavity.

Here you see that this is an amplifier. So, already you have a loop, low amplitude RF signal microwave signal so you are coupling that to this buncher cavity. Now you want that this thing should be amplified. So, already that means some klystron, some magnetrons someone has produced it you are now taking that and through a loop coupling you are coupling that to the RF. So, RF in this case will resonate and this RF signals this RF signal frequency and resonating frequency is same.

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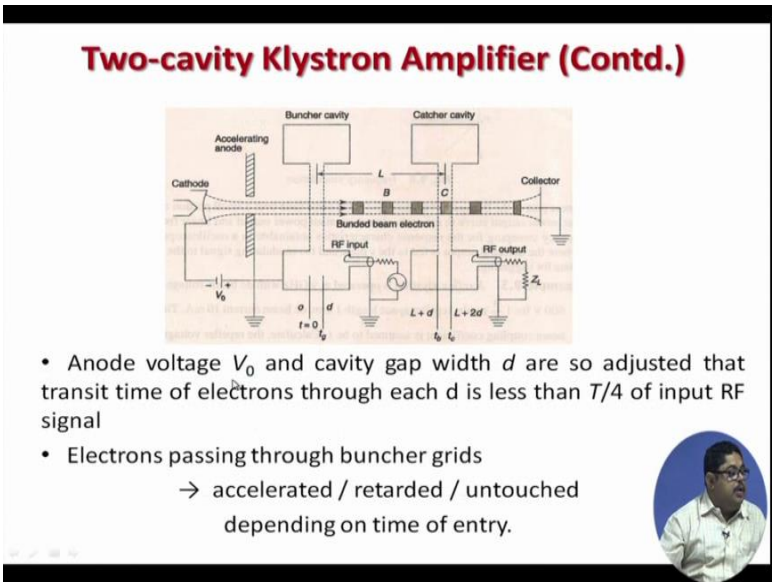

And anode voltage V 0 and cavity gap width d. So, anode voltage V 0, anode voltage this V 0 and cavity gap width d where is d, d this is d. So, cavity gap width d that is why we adjusted that transit time of electrons through each d is less than t by 4 of input RF signal. What does that mean? that means, they are all seeing the same type of either all are accelerating or all or decelerating. Now electrons passing through buncher grids depending on time of entry they will be accelerated, retarded or untouched. So, we see here the diagram that the real this one when it is t g plus RF field is maximum here.

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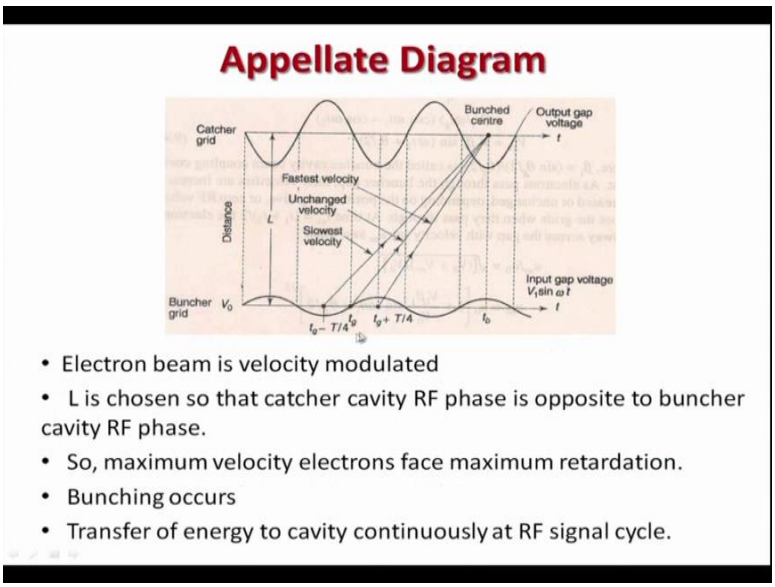

So, this electron will have fastest velocity than the 1 this t g that is our 0 velocity RF field it is showing. So, that will be unchanged velocity and this is the slowest velocity will be this. So, they all are retarded and where that retardation takes place. So, l is chosen, l is this bit space between the two cavities that l is chosen. So, that catcher cavity RF phase is opposite to buncher cavity RF phase, buncher cavity and catcher cavity. So, whatever RF signals we are giving, but this catcher cavity is l is such that the RF phase is different opposite exactly. So, maximum velocity electrons this is the maximum velocity electrons it is coming here and seeing the field you see that it will be since the phase is opposite it will give, it will phase maximum retardation.

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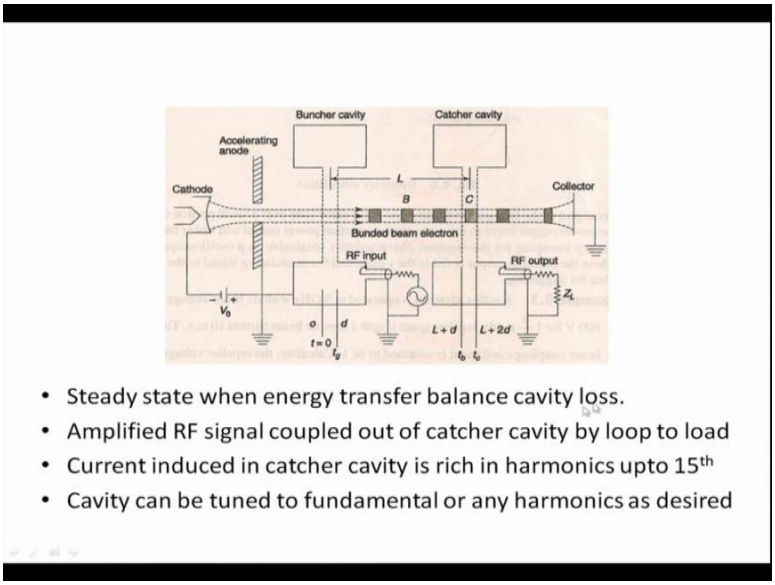

Similarly, the minimum one that phase the minimum retardation, now bunching occurs and due to that bunching occurs transfer of energy to cavity continuously at RF signal cycle. Steady state when energy transfer balance cavity loss amplified RF signal is coupled out of catcher cavity, you see that out of catcher cavity we take this signal out. So, this was signal in, this is an amplified signal out and the electron beam they gets collected because the otherwise the circuit cannot get completed. Now current induced in catcher cavity is rich in harmonics up to 15; that means the after bunching when the extraction takes place. So, up to 15th harmonic time, 15th harmonic frequency they are also present. So, you can tune the cavity, this cavity can be tuned to fundamental or any harmonics as desired and you can study the operation.

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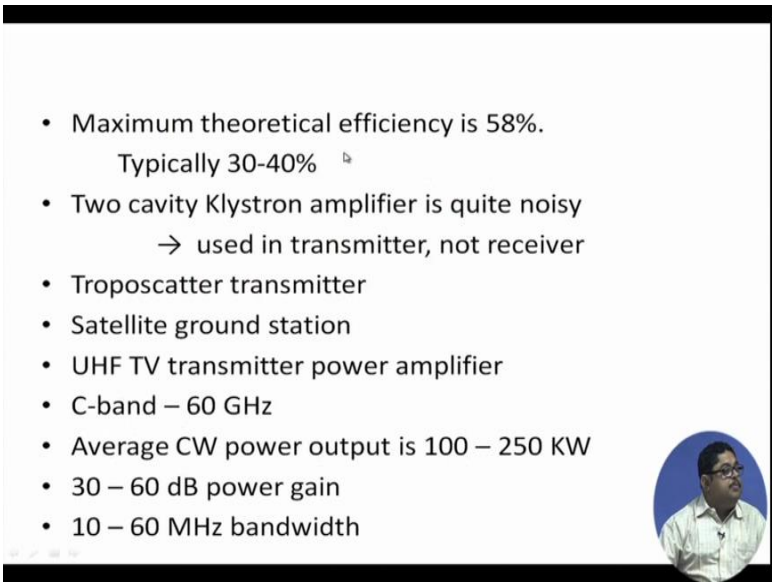

Maximum theoretical efficiency is 58 percent, typically you get 30 to 40 percent efficiency from this amplifier, 2 cavity klystron amplifiers is quite noisy used in transmitter it is quite noisy. So, you cannot use it in good receiver or sensitive receivers because they require low noise devices. In troposcatter transmitter for atmospheric studies it is used, satellite ground station is also used this amplifier. UHF TV transmitter power amplifier etcetera, C-band to 60 giga hertz, C-band is 4 to 6 giga hertz, this 60 giga hertz you can the satellite ground station they can use it. Average CW continuous wave power output is 100 to 250 kilo watts. So, it gives a good power output 30 to 60 dB power gain not joke. You see that 10 dB power from a small signal thing vary, but klystron can give you easily 30 to 60 dB power gain, 10 to 60 megahertz bandwidth.

Another amplifier actually this is better than klystron in many senses. So, this called traveling wave tube amplifier here if you remember that all the 5 process takes place simultaneously at the energy creation. So, it is a broad band amplifier because here we do not have any cavity type non-resonance structure here what we have instead of that cavity thing resonance thing, here we have an helix; that means, a coil actually it placed one by one coil that is placed axially that is called a helical structure. So, it is again a periodic structure so electron beam electron is going and it is seeing some periodic thing it will become slow wave structure. Now due to this slow wave, the wave is having a slow thing electron beam from cathode that continuously interacts with this slow wave RF field.

This helix as a field so RF input is given to this helix here, here RF input given to this helix; now actually in other structures non-slow wave structure you see the electrons they travel will speed of light, but electrons travel with much less speed because they have there have some mass, but the RF things they are very higher than sea. So, interaction is difficult, but if you slow down then they can interact that is the principle of travelling wave tube electron beam from cathode continuously interacts with axial RF field of helix both velocity and density modulation takes place and axial focusing of electron beam by axial dc magnetic field produced by longitudinally distributed magnet.

So, you see this is the longitudinally distributed magnet is produced, input RF injected in the input of input of helix beam voltage is, adjusted that beam velocity is slightly greater than RF velocity so that interaction can take place. Now electron beam velocity is just slight greater than RF velocity energy transfer throughout the whole journey the RF beam RF field that extracts energy from this electron.

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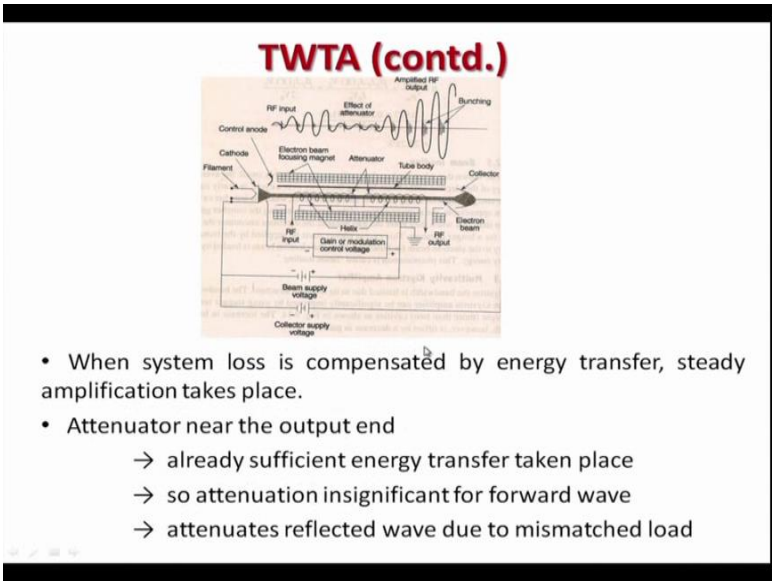

When system loss is compensated by energy transfer steady amplification takes place. Now there is also an attenuator at the output end of the tube. Now why there is a need for attenuator in an amplifier? the point is this is placed when already sufficient interaction of RF field with electrons takes place. So, most of the electron that are going to the collector they have given their energy. So, that time if the attenuator is there it cannot take much energy, but what happens in the load suppose when we are putting the RF

output to the load there may be some mismatch because load is not in our hand. So, that load if it is there is mismatch there will be some reflected wave those reflected waves since the attenuator is near the output end those reflected waves will be attenuated so that they do not go and disturb the gun. So, that is why the electron gun will be then disturbed that is why the attenuation. So, attenuation is insignificant for forward wave, attenuates reflected wave due to mismatched load.

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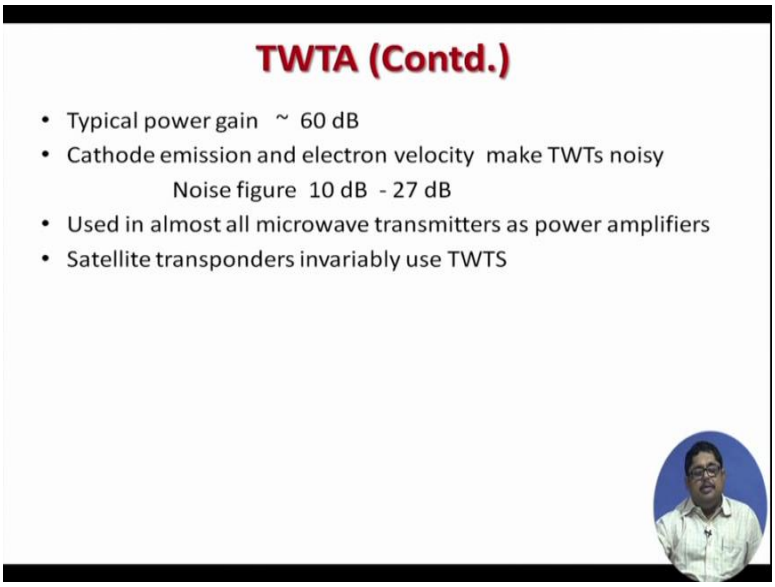

Typical power gain of travelling wave tube amplifier is 60 dB cathode emission and electron velocity make TWTs noisy. So, noise figure of a TWT is typically 10 dB to 27 dB, quite noisy because we require for a good amplifier particularly l n a type of application will require 0.3 0.4 dB attenuation, but it is quite noisy; 10 dB is quite noisy used in almost all microwave transmitters as power amplifiers.

Nowadays TWT is the main practice. if you go to any cell phone this base station of any cellular phone if you see when before pumping the power to the outside they from the web guide they are taking the power and then there is a TWT amplifier then they are (Refer Time: 23:40). In all satellite either transponder or the ground station the final power amplifier is invariably troubling wave tube. So, TWTA is the amplifier. So, we have seen 2 amplifiers, one is 2 cavity klystron amplifiers you can use klystron as an amplifier or you can TWTA. So, there is a comparison between them.

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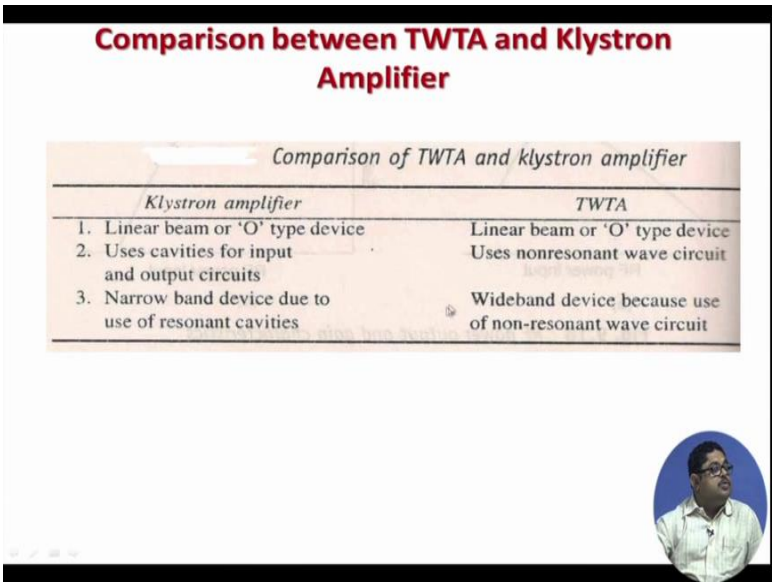

So, both klystron amplifier and TWTA they are 'O' type device uses cavities for input and output circuits klystron amplifier that TWTA does not use that uses an non-resonant wave circuit basically uses helix.

Narrow band device due to use of resonant cavities; it is a resonant device you have a good view that is why the narrow band device, but wide band device because use of non-resonant wave circuit. So, it can give you wide band thing. So, nowadays TWTA is becoming more popular of this that is now in a signal generally our signal bandwidth is increasing day by day the signal bandwidth is more because people want to from more information in the bandwidth. So, if higher iterate also means higher bandwidth. So, for that amplifier signal TWTA will perform better in klystron amplifier. So, that is why TWTA is getting every day over the klystron type of amplifier.

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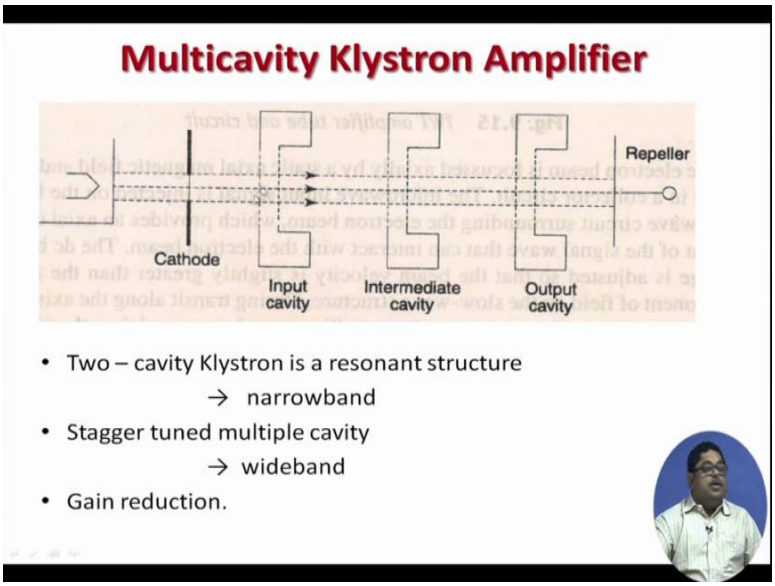

Now, to counteract that klystron also has improved. So, it has instead of 2 cavity klystron there is multi cavity klystron you see, there is an input cavity there is output cavity then there are several cavity; that means, this is your cavity what that call bunch, buncher cavity and catcher cavity. So, we can say that this is the buncher cavity and this is the catcher cavity this is the intermediate cavity. So, 2 cavity klystron is change to stagger tuned multiple cavity that is makes you to wide band, but obviously if you do like this then any wide band thing means it is gain is reduced because gain bandwidth product that should be same. So, if you increase the bandwidth the gain will be reduced that is happening, but this is a good up gradation of cavity klystron.

Thank you.