Topic 4
MICROWAVE SOURCES
Course Learning Outcomes (CLO)

CLO1
Explain clearly the generation of microwave, the effects of microwave radiation and the propagation of electromagnetic in a waveguide and its accessories.

CLO4
Display good communication skill through presentation of any given essay question.
Lesson Learning Outcomes

Upon completion this topic, students should be able to:

i) State the sources of microwaves
ii) Draw the schematic diagram of the sources.
iii) Explain the operation of the sources
Sources of microwaves

There are TWO types of sources that used to generate microwave signal:

i) Microwave Tube shape
ii) Microwave diode semiconductor
The tube is a device used to control a large signal with a smaller signal to produce gain, oscillation, switching and other operations.

Microwave tube consists of:

i) Klystron
ii) Magnetron
iii) Traveling Wave Tube (TWT)
Microwave diode semiconductor

i) Tunnel diodes

ii) Gunn diodes

iii) IMPATT (impact avalanche & transit time)

iv) LSA (Limited Space charge Accumulation)
Microwave diode semiconductor

v) Varactor diode  
   (variable capacitor diode)

vi) PIN diode (P Intrinsic N)

vii) Schottky Barrier Diodes
Klystron

• Microwave energy is produced by a klystron tube.

• Invented by Varian brothers just before the second world war.

• Klystron belong to a class of devices known as velocity modulation devices.
• Velocity modulation is the process that causes the velocity modulated electron and electron would be collected gradually.

• Klystron is a vacuum tube that uses a microwave resonant cavity to produce a modulation (change) the velocity of the electron beam and lead to the reinforcement.
It can be divided into three (3) groups:

i) Two cavity klystron
ii) Multicavity klystron
iii) Reflex klystron
Two cavity klystron
Two cavity klystron

Drift Space

"Buncher" Cavity
Density of Electrons
Electron Beam

"Catcher" Cavity

Cathode
Anode
Microwave Input

Collector
Microwave Output
The two cavities are called **buncher cavity** and **catcher cavity**.

The two cavities is supplied with $V_0$ while the collector is at $V_0 + \delta V$.

The collector is set at a higher potential so that electrons emitted from the cathode are accelerated towards the collector.

The space between the two cavities are called **drift space**.
Principle of operations

- The electron beam is injected into a first (buncher) cavity.
- The signal will produce an appreciable RF voltage which will set up a magnetic field in the cavity.
- Electron passing through the gap will interact with this field and change their velocity.
- Since the velocity of electrons is modulated by the field, klystrons are called velocity modulated devices.
• The change in velocity will either accelerate or decelerate the electron in the drift space.

• The electron will then bunch at the second cavity (catcher) and collected by the collector.

• The bunching will result in the electrons giving up energy to microwave signal in the catcher cavity.
Multi cavity klystron
construction

- The multi cavity klystron consist of a glass envelope in which there is an electron gun composed of heater and cathode.
- After the electron gun there are two focusing electrodes used to keep the electron beam in the center around the glass envelope.
- There are two cavities known as buncher and catcher cavity
• Between the cavities around the glass envelope, a magnet is used in order to keep the electron beam in the center and in concentrated form at the end inside the glass envelope.

• There is anode used to attract the electrons emitted from the cathode.
Principle of operation

• When switch on the circuit, the electrons starts emitting from the cathode.
• These electrons move at a uniform speed towards the anode until they are attracted by it.
• Apply the R.F input signal to the buncher cavity with the help of loop coupling.
Principle of operation (cont…)

• When this negative half cycle is applied to the buncher cavity, the negative charges will develop and the speed of electron will be reduced between the cathode and cavity.

• As a result the bunch of electrons will be formed near the buncher cavity.

• Now this bunch will travel towards the anode.
Principle of operation (cont...)  

• At the movement when the positive half cycle is applied, the speed of electrons will increase from the previous condition.

• These electrons will join the bunch produced by negative half cycle and the field strength of the field of the bunch will further increase.
Principle of operation (cont...)

• In this manner bunches will continue to be form. when the R.F signal is present at the buncher cavity.

• when the bunch of electrons reaches in front of catcher cavity, due to its strong field strength the excitation of this cavity will take place and we will get an amplified output from the catcher cavity.
Application of multi cavity Klystron

- This type of klystron is mostly used for the purpose of amplification of microwave length of frequencies.
- It means that the high frequencies can be amplified by multi cavity klystron. Which is impossible and not feasible to use other components for this purpose.
Reflex klystron
Three power sources are required for reflex klystron operation:

i) filament power,

ii) positive resonator voltage (often referred to as beam voltage) used to accelerate the electrons through the grid gap of the resonant cavity,

iii) negative repeller voltage used to turn the electron beam around.
Construction (cont....)

• The *reflex klystron* contains a *REFLECTOR PLATE*, referred to as the *REPELLER*, instead of the output cavity used in other types of *klystrons*. 
Principle of operations

• The resonant cavity is set at a +ve potential.
• Electrons are emitted from the cathode as before and accelerated towards the cavity by the positive voltage.
• These electrons reflected by the negatively charged reflector
Principle of operation (cont..)

- The electron beam is modulated as it was in the other types of klystrons by passing it through an oscillating resonant cavity, but here the similarity ends.
- The feedback required to maintain oscillations within the cavity is obtained by reversing the beam and sending it back through the cavity.
Principle of operation (cont..)

- The electrons in the beam are velocity-modulated before the beam passes through the cavity the second time and will give up the energy required to maintain oscillations.
- The electron beam is turned around by a negatively charged electrode that repels the beam.
Principle of operation (cont..)

• This negative element is the repeller mentioned earlier.

• This type of klystron oscillator is called a reflex klystron because of the reflex action of the electron beam.
<table>
<thead>
<tr>
<th>Two cavity klystron</th>
<th>Reflex klystron</th>
</tr>
</thead>
<tbody>
<tr>
<td>Can act as both amplifier and oscillator</td>
<td>Can act as only an oscillator</td>
</tr>
<tr>
<td>Need a buncher cavity and a catcher cavity</td>
<td>Needs only one cavity</td>
</tr>
<tr>
<td>Bunches electron in forward direction</td>
<td>Bunches in the reverse direction using a reflector</td>
</tr>
<tr>
<td>Needs input signal</td>
<td>No need input signal</td>
</tr>
</tbody>
</table>
magnetron

• Invented by Randall and Boot in 1946.

• The magnetron is the first high power microwave oscillator to be developed.

• The invention of magnetron made microwave radar system possible during the 2\textsuperscript{nd} world war.
Cavity resonators

Probe

Cathode

Anode

Fig. 1. - Section of Magnetron Construction

magnetron
The anode is constructed of a solid copper ring into which several resonant cavities are machined. The cavities are a set of quarter-wave resonant lines, the open ends of which are at the inner surface of the anode block. The resonance ensures that when oscillation take place, a strong RF electric field is set up at the inner surface.
Image of magnetron
Principle of operation

- Electrons are emitted from the cathode and are accelerated towards the anode.
- Along the way the electrons will experience a magnetic force perpendicular to its direction of motion and a radial electric field.
Principle of operation (cont...)  

- Their motion is therefore spiral, then it will form axial bunches, and when they get to the cavity entrances, they give up their kinetic energy.
- The energy in turn makes the cavities oscillate.
Travelling Wave Tube

• Invented by Kompfner and Pierce, U.S 1946.
• Used as an amplifier and can operate over bigger bandwidths.
• Provide the best performance over a wide frequency range (low to medium power applications)
• Very popular for broadband satellite and terrestrial systems.
construction
The travelling wave tube, TWT, can be split into a number of separate major elements:

- Vacuum tube
- Electron gun
- Magnet and focusing structure
- RF input
- Helix
- RF output
- Collector
Principle of operation

- The travelling wave tube is contained within a glass vacuum tube. This obviously maintains the vacuum that is required for the operation of the TWT.
- The electron gun comprising primarily of a heated cathode and grids.
- A magnet and focusing structure is included in order to make the electrons travel as a tight or narrow beam along the length of the travelling wave tube.
The RF input consists of a direction coupler which may either be in the form of a waveguide or an electromagnetic coil. This is positioned near the electron gun emitter and it induces current into the helix. Helix is an essential part of the traveling wave tube. It acts as a delay line, in which the RF signal travels at near the same speed along the tube as the electron beam.
• The electromagnetic field due to the current in the helix interacts with the electron beam, causing bunching of the electrons in an effect known as velocity modulation and the electromagnetic field resulting from the beam current then induces more current back into the helix.

• In this way the current builds up and the signal is therefore amplified.
• The RF output from the traveling wave tube consists of a second directional coupler.

• Again this may either be an electromagnetic coil of a waveguide.

• This is positioned near the collector and it receives the amplified version of the signal from the far end of the helix from the electron gun or emitter.
• An attenuator is included on the helix, usually between the input and output sections of the TWT helix.
• This is essential to prevent the reflected wave from travelling back to the cathode of the electron gun.
• The collector finally collects and absorbs the electron beam.
• It is in this area that high levels of power may be dissipated and therefore this section of the travelling wave tube can become very hot and will require cooling.
Travelling wave tube applications

• There are many areas in which TWT amplifiers are used.
• They are an ideal form of RF amplifier for satellites and as a result they are extensively used for satellite transponders where low levels signals are received and need to be retransmitted at much higher levels.
• In addition to this TWT amplifiers are used in microwave radar systems where they are able to produce the high levels of power required.

• Traveling wave tube, TWT technology is also used for electronic warfare applications.

• In these applications the grid on the travelling wave tube may be used to pulse the transmission.
End of session 1
Tunnel Diode

SCHEMATIC DIAGRAM OF TUNNEL DIODE
IMAGE OF TUNNEL DIODE
VI CHARACTERISTIC OF TUNNEL DIODE

\[ r_{\text{diff}} < 0 \]
• A **tunnel diode** or **Esaki diode** is a type of semiconductor diode that is capable of very fast operation, well into the microwave frequency region, by using the quantum mechanical effect called tunneling.

• These diodes have a heavily doped P-N junction only some 10 nm (100 Å) wide.
Principle of operation

• A Tunnel Diode is a PN junction that exhibits negative resistance between two values of forward voltage.
• The tunnel diode is basically a PN junction with heavy doping of P type and N type semiconductor materials.
• Tunnel diode is doped 1000 times as heavily as a conventional diode.
• Heavy doping results in large number of majority carriers.
• Because this large no of carriers, most are not used during initial recombination that produces depletion layer.
• It is very narrow. Depletion layer of tunnel diode is 100 times narrower.
• Operation of tunnel diode depends on the tunneling effect
• The movement of valence electrons from the valence energy band to the conduction band with little or no applied forward voltage is called tunneling.
Conduction band

Valence band

Holes

Applied forward bias

Barrier height

(a)

(b)

(c)

(d)
As the forward voltage is first increased, the tunnel diode is increased from zero, electrons from the n region tunnel through the potential barrier to the potential barrier to the P region.

As the forward voltage increases the diode current also increases until the peak to peak is reached. $I_p = 2.2 \text{ mA}$. Peak point voltage $= 0.07 \text{ V}$
• As the voltage is increased beyond $V_p$ the tunneling action starts decreasing and the diode current decreases as the forward voltage is increased until valley point $V$ is reached at valley point voltage $V_v= 0.7V$ between $V$ and $P$ the diode exhibits negative resistance i.e., as the forward bias is increased, the current decreases.

• When operated in the negative region used as oscillator.
A Gunn diode is also known as a transferred electron device (TED).

It is a form of diode used in high-frequency electronics.

It is somewhat unusual that it consists only of n-doped semiconductor material, whereas most diodes consist of both P and N-doped regions.
• In practice, a Gunn diode has a region of negative differential resistance.

• Gallium Arsenide Gunn Diodes are made for frequencies up to 200 GHz whereas Gallium Nitride can reach up to 3 THz
Image of Gunn Diode
Current-voltage (IV) curve of a Gunn diode.
Gunn Diode Construction

- The top and bottom areas of the device are heavily doped to give N+ material.
- The device is mounted on a conducting base to which a wire connection is made.
• It also acts as a heat sink for the heat which is generated.

• The connection to the other terminal of the diode is made via a gold connection deposited onto the top surface.
• The centre area of the device is the active region.
• This region is also less heavily doped and this means that virtually all the voltage placed across the device appears across this region.
• In view of the fact that the device consists only of n type material there is no P-N junction and in fact it is not a true diode, and it operates on totally different principles.
When a voltage is placed across the device, most of the voltage appears across the inner active region.

As this is particularly thin this means that the voltage gradient that exists in this region is exceedingly high.
• It is found that when the voltage across the active region reaches a certain point a current is initiated and travels across the active region.

• During the time when the current pulse is moving across the active region the potential gradient falls preventing any further pulses from forming.
• Only when the pulse has reached the far side of the **active region**, the potential gradient **will rise**, allowing the next pulse to be created.

• It can be seen that the time taken for the current pulse to traverse the active region largely determines the rate at which current pulses are generated, and hence it determines the frequency of operation.
• For a normal diode the current increases with voltage, although the relationship is not linear.

• On the other hand the current for a Gunn diode starts to increase, and once a certain voltage has been reached, it starts to fall before rising again.

• The region where it falls is known as a negative resistance region, and this is the reason why it oscillates.
GUNN DIODE

ADVANTAGES

- It has much lower noise than IMPATT diodes
- Gunn amplifiers are capable of broad-band operation.
- Higher peak-to-valley ratio in its –ve resistance characteristics.
- High fundamental frequency operation.
- Increased efficiency.
APLICATIONS

- Gunn diode oscillator as low & medium power oscillator in microwave receivers & instruments.

- As pump source in parametric amplifier.

- High-power Gunn oscillators (250-2000mW) are used as power output oscillators.
- Frequency modulator in low power transmitter.
- In police & CW-Doppler RADAR, burglar alarms, aircraft rate-of-climb indicators.
- YIG (yttrium-iron garnet) -tuned Gunn VCOs for instrument applications.
IMPATT DIODE

• **An IMPATT diode** (IMPact ionization Avalanche Transit-Time) is a form of high-power diode used in high-frequency electronics and microwave devices.

• They are typically made with silicon carbide owing to their high breakdown fields.

• IMPATT diodes operating frequency is in the range 3 to 100 GHz.
• The word IMPATT stands for impact avalanche transit time. IMPATT diodes are made on silicon, silicon carbide, GaAs and InP.

• IMPATT diodes not that long ago were an important technology. IMPATT holds many of the world's records for solid state power, either as oscillators or as amplifiers. However, the complexity of creating an IMPATT transmitter is such that few could afford one. Waveguide is most often used to combine many IMPATTs.

• The diode is constructed on P+, N and N+ layers. It is operated at reverse bias. Impact ionization happens when the applied electric field causes a free electron to hit an atom in the lattice and release an electron-hole pair.
Sampai sini jer dulu.... Nanti sambung balik and send semula deh