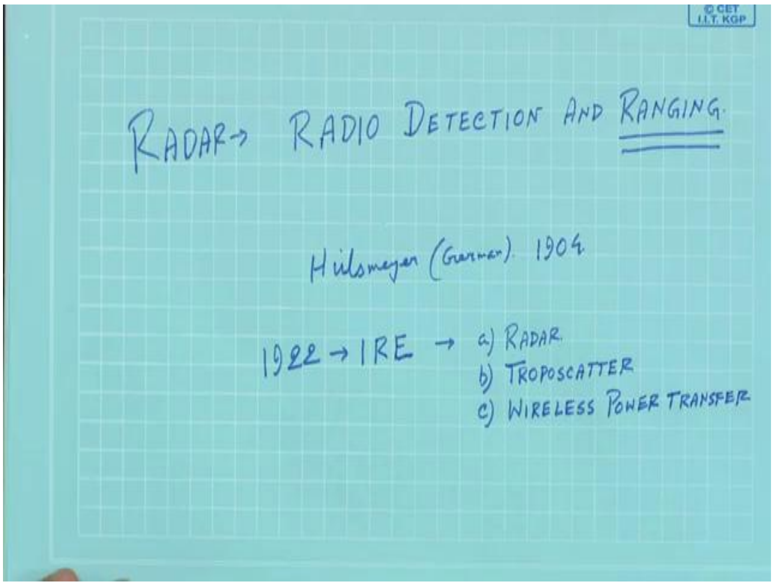
Principles and Techniques of Modern Radar Systems
Prof. Amitabha Bhattacharya
Department of E & ECE
Indian Institute of Technology, Kharagpur

Lecture - 01
Historical Development and Application

Key Concepts: Concept of Radar, Evolution of Radar System, Application of Radar

Welcome to the 1st lecture of the course on radar, Modern Radar Systems and Applications. So, as you all know that a radar is an acronym, it stands for radio detection and ranging.

(Refer Slide Time: 00:35)



So, you see that the as the name suggests, so this is the acronym for radar. So, as the name suggests that it is primarily a detection tool. And what is the source of that detection mechanism? That is the radio waves. So, basically electromagnetic wave, so by that it detects. And also, a very important function is it can determine range. So, a radar won’t be called a radar if it cannot measure range, if it only detects it wouldn’t be a radar. Ok, it is a complete microwave system.

Basically, you can consider that it is an extension of our eye. Our eye actually gives us information about various things that is in the vicinity of us, in front of us etcetera, but radar extends that capability of an human eye because it gives you more range. Actually typically our eye can see up to let us say 1, a bit less than 1 kilometer not more than that, if you stand in a plane field where you have that horizon in front of you less than 1 kilometer you can see by your eye. But in radar actually that range get extended. You can go 500 kilometer, 1000 kilometer, even 5000 kilometer radars are available etcetera.

Also, with the satellite technology from the very top of the earth if you see from 36,000 kilometer also you can see. So, all these are extension of our eye in the range. Then a, our eye it can see only if there is a light present; that means, it is also electromagnetic radiation, but light is a particular type of electromagnetic radiation of particular frequency.

So, but the problem is our eye cannot see where there is no light. In the daytime there are a lot of sunlight, so we can see, but in the night time if you do not switch on some other source of light then you cannot see. But radar doesn't suffer from these. Radar also works on electromagnetic radiation, but since its frequency range is such that it can see in darkness also.

So, even if when normal light is not there, radar can see, so that is an important extension of the eye. Then it can see in haze, fog, snow, rain. Normal eye cannot clearly see in all these impairments, but radar can see. But then, what is the drawback of the radar, definitely our eye has a very good resolution. We can see each point separately. Radar cannot do that; radar is much poorer to eye in terms of resolution.

Now, actually the if we just look back in the history of development of radar, actually you know that Heinrich Hertz, he invented or he proved that electromagnetic radiation is possible and by that he showed that communication is possible. He is also did the first experiment to show that if you have a metallic or a dielectric object and if an electromagnetic radiation falls on that then that thing gets reflected.

But he did not understood the implication of that. So, in 1866, he made that experiment. But, so that we consider that that is the fundamental physics experiment that electromagnetic waves get reflected from a body, but there was no discovery of this radar till 1904.

That means, you can see almost after 38 years there was a person called Hulsmeyer; Hulsmeyer was a German and he was the first who understood that these detection of radio waves can be used to detect a ship. Actually, from the ship, the ships are made generally wood nowadays good material, but in those days wood or some metallic portions. So, from that there is a sizable reflection, so it can be detected.

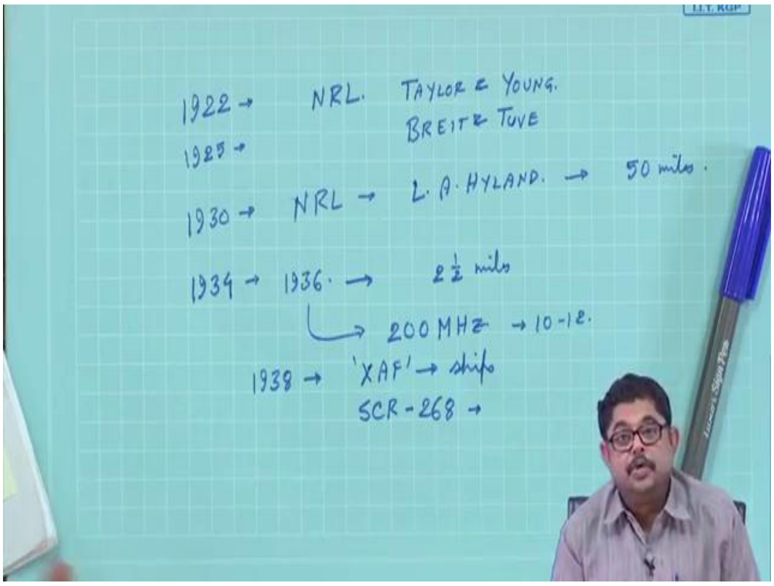
So, in 1904, he made a patent on that and actually he called it obstacle detector and he approached German navy and that time with his technique you can detect a up to 1 mile. If the ship is away up to 1 mile it could have been detected. So, German navy did not show interest they said that we can see up to 1 kilometer, so how much we are gaining some 2 and half times gaining of range so, that is not very impressive, so they discouraged him. So, actually the Germany lost the race for developing this radar by this thing.

The first person who understood the implication of this experiment was again a very famous name Marconi, who was famous for understanding the radio. Similarly, he was also instrumental to understand what is the implication of this for radar. Actually, he gave a speech in 1922; in 1922 he gave a speech before institute of radio engineers which was a precursor to our present day IEEE. Actually this thing is available. This is in internet you can see this speech in IREs, in 1992 speech volume, those are given in IEEE site also.

So, there he understood the implication of these for radar and actually in that speech he also had, he listed three things. One is this radar principle that this can be used for detection of ships, then he also said that there is an importance of troposcatter; that means, in troposphere there is a scattering which helps to extend the line of sight of any radio wave propagation and also, he said about wireless power transfer. All these three were quite revolutionary in concept. And the last one wireless power transfer still people are researching on these.

So, you see that importance of Marconi was the speech where he address a radio engineers and said that these are the fields which are very important you concentrate on that. And taking this inspiration from him actually some American scientist who were also working for American navy they were started work and in 1922 itself to NRL scientists; NRL stands for Naval Research Lab of USA. Their name was Taylor and Young; Taylor and Young they tried to confirm Marconi experimentally.

(Refer Slide Time: 09:27)



So, a wooden ship was detected at 60 megahertz. That time the low power sources were only available and it was a continuous wave source, but here also initially the American authorities, their naval authorities they did not permit them to extend this work. And what happened is in 1925 another scientist, another two scientists their name is Breit and Tuve, they could that is for a different contest they could measure the height of ionosphere by this radio wave the same principle and they could not relate it to radar, but it was an important thing that range can be measured by these because you see previously only it was a detection now the range also was done by Breit and Tuve.

And in 1930, now the naval research lab they understood the importance of detection of radars. Actually, in those days you see always if an enemy ship etcetera is coming, it is as early as possible if you can detect it you can have some measure to counteract with it. So, that is, but in those days instead of radio waves actually sound waves were used, so the sound of the thing comes. So, sound locators, now unfortunately sound can be heard from distance of 20 kilometers or something.

So, unless and until a radar crosses that 20 kilometer range, then it does not become lucrative to use radar in place of sound locators. So, that was done by in 1930 another NRL scientist his name is L A Hyland, he actually found out that detection range he caught was 50 miles. Now, this was a big achievement that from 50 miles away if you can detect an object then you have lot of time to act to oppose it etcetera.

So, now unfortunately what these people who were using those time the electronics for sending pulse waves were not there. That is why they were sending continuous wave. When we will see continuous wave radars later, the problem is continuous wave radars can detect an object, but cannot calculate its range.

So, for that actually the advancement of pulse radar was necessary, so for that mankind had to wait, but not long. Only after 4 years, in 1934 pulse radar experiment was performed; obviously, the early experiments were failure because that time the receiver technology, actually you see this time already the radio receivers were available, but that radio receivers were all operating on continuous small basis; that means, sinusoidal waves continuous and sinusoidal waves sending.

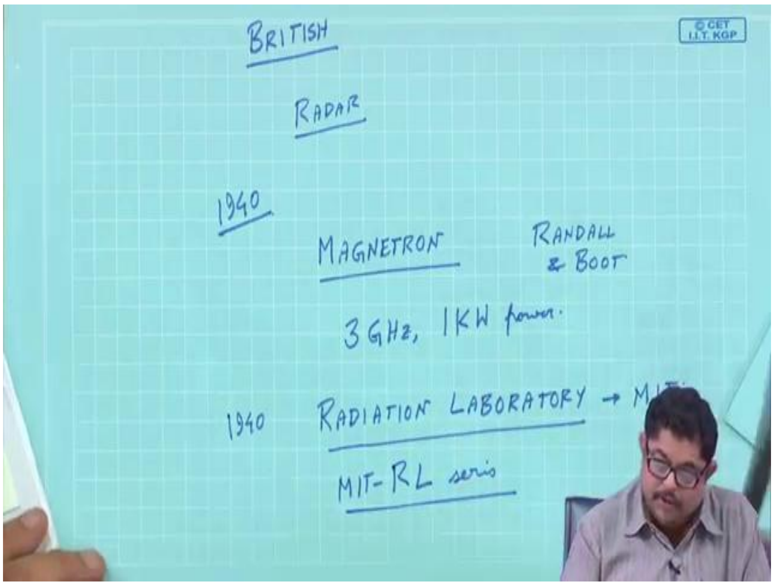
They were not designed for pulse detection. That is why initially they were failure, but from 34 up to 1936 the pulse radar things came. So, that time again, for the pulse radar, the initially the range was less, the first pulse radar the only 2 and half miles were there, but immediately afterwards they perfected the things and they understood that they need to go higher up in frequency because that will make the whole thing meaningful to place in radars etcetera.

So, in 1936, we already got a high in those days it was a really high frequency 200 megahertz radar and it could achieve a range of 10 to 12 miles. And thereafter again the more and more high power things were coming by 1938, remember 1938 is; that means, already the second world war is coming, 1939 it will start.

So, that time in 1938 US army they had got a pulse radar system that is called initially it was called XAF system that in battleships world war 2 that battleships they install that and also there was another system called this is in aircraft this were in ships and SCR 268. So, all the modern USR means anti-aircraft they were anti-aircraft fire control there they had this radar and. So, already you see you see the importance of fundamental research since US naval people they researched on radar by the second world war they were ready with the system, a radar which can detect.

Similarly, actually it should be said that in I think all of you know the pearl harbor incident where the this in pearl harbor there was a harbor where, where the American things were bombed. So, the radars could detect the planes, but that detection was done that time the since the range was small. So, when the aircrafts came very near then only they could detect, but they could detect. So, that showed that, it was very really necessary to develop. And there are also another research going on in British system, so what I said now was American system.

(Refer Slide Time: 16:49)



So, British they are they also understood because they were a major power before world war 2. So, the they were trying to get those as I said that they had sound locators which can see up to 20 miles, but due to impending war they were also understood that radar should be developed. So, they were developing and by the second world war they also had their systems, radar systems were installed in British army, but one thing they understood that whatever the range of the radar that is not very high.

And so, they understood that British understood and American people also understood that they need to collaborate to make this radar more range. So, that more time can be gained to detect a coming aircraft and so, they decided to collaborate, but that was in the midst of the world war in 1940 they both collaborated and actually by that time British had invented the main bottleneck for this radar technology, that was impending this radar technology that was the high power microwave source because you see that at high power; that means, in that gigahertz type of power that is a microwave and will come next.

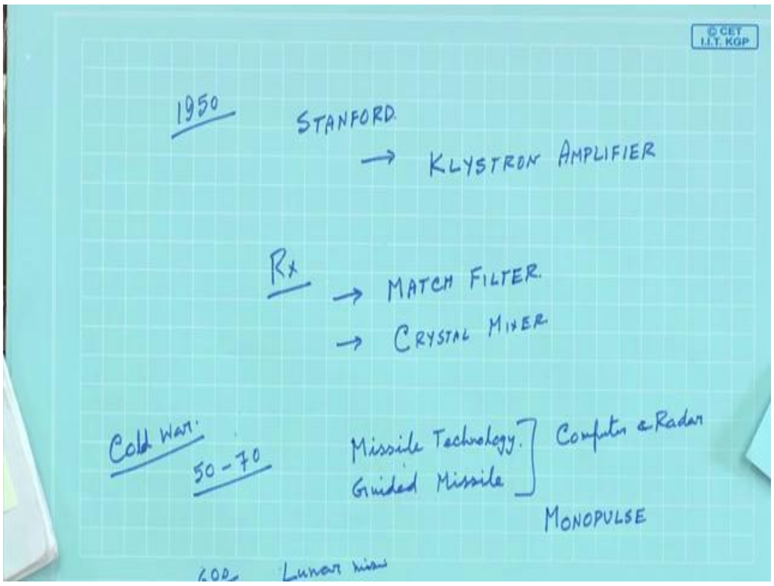
So, there actually the normal principles by which our normal low frequency, electronic oscillators work that does not work, because that is a distributed in gigahertz thing many things are principles that are applicable for low frequency things does not work. So, high frequency and high power sources based on this was not available, but by 1940 actually the British people they have invented that high power source that is called magnetron, in microwave courses I think you have only.

This is a very high power very good source, but this is not a very stable source. But that time that was not the point, point was magnetron was invented by two very famous people one is Randall and another is Boot, British people. They made a magnetron 3 gigahertz and it could give 1 kilowatt of power; it is a good amount of RF power in those days. And what that collaboration between the British and US, that the result of that is this whole magnetron thing was given to the Americans.

And Americans actually geared up they established in the same year 1940, the there is a radiation laboratory that was created by US government, radiation laboratory at MIT Massachusetts Institute of Technology. And actually, all the radar development that has taken place after that for the next decade that will be done by these. So, this radiation laboratory got this MIT radiation laboratory.

So, the magnetron was given to them, then they could the other systems they developed and they published a book this is called radiation, MIT Radiation Laboratory series of books where all facets of microwave technology that time they could develop, but that time actually war almost ended. So, it was not used in second world war, but just after second world war the outcome started coming and now the full-fledged radars were available and the whole microwave technology also come into there.

(Refer Slide Time: 20:55)



There after another development came in 1950s that time in Stanford laboratory. Actually, Stanford laboratory was working on particle physics that was also a basic physics research. And to have the experiment they had a instrument called linear accelerator where they give a particle very high acceleration in that, and there they used, there they invented the another high power source as well as amplifier that is klystron amplifier. And that will replace this magnetron because magnetron was not a stable source, but this klystron was a stable source we will see later what is the use or what is the implication of the stable source in the pulse radar technology.

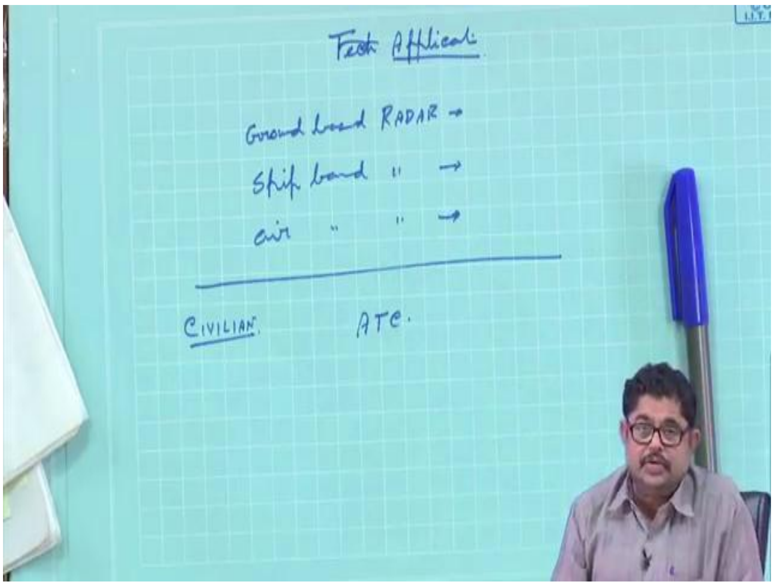
So, once this klystron amplifier was given by Stanford University. So, the radar got its full technology ready, and also there were by the by this whole effort of radar people at MIT etcetera, the receiver technology was also improved. You see match filter was developed by radar people for very low snr detection this match filter is necessary. Actually, radar is a more complicated problem than communication because in communication transmitter sends the signal it goes to the receiver. Whereas, in the radar transmitter sends the signal, the object gets the signal, scatters back that signal, again it comes to the radar. So, it is a two way journey, so lot of loss takes place, so very weak signal came.

Now, how to detect such a weak signal that was not possible unless and until match filter was invented? Actually, the radar people for them it was a life and death problem that how to detect a very low signal. So, they found out that match filter is a best filter which can detect for a given very low SNR this is the best possible filter. We will see match filter concepts later. So, this was one important thing, then there was the in the receiver side, there was crystal mixer, then also the low noise amplifiers etcetera. So, those were by that time developed. So, the radar technology fully matured in 60s.

Now, after the world war there was a cold war between two superpowers and that time actually, so we can say that the in the cold war is; that means, you can see roughly from 50s to 70s. This time there were two technologies due to cold war this missile technology that time all these intercontinental ballistic missile etcetera were developed and also guided missile. So, this missile technology needed very precise tracking etcetera.

So, in this time computer and radar they got merged. So, in radar computer things came and with the help of that very good tracking started. We will see this well we will see the monopulse concept. The monopulse is a very good tracking thing where very precisely you can detect the angular location of an object, and also along with cold war there was a in 60s there were also the lunar missions. So, lunar missions again required these tracking's, as well as very high-power sources etcetera. So, high power sources large antennas these all came into being. Now, we will see that what are the major applications of this radar technology.

(Refer Slide Time: 25:25)



Actually, this is a bit of introduction. So, technology wise sorry application wise you see there are the first thing is ground based radar. So, they are used for mainly these defense type of thing, that detection and location of aircraft and space targets also fire control. Fire means to have a countermeasure; that means, when is enemy is coming you try to fire upon him. So, for that these ground-based radars are used.

Then ship based radar, so they are used for detecting naval objects, aircraft navigation, yet to locate shore line or boys when you are voyaging etcetera. Then there are air-based radar airborne radar also called. So, the detection of aircraft from air, so that means, you gain an advantage because more early you can detect an aircraft.

You can also detect ships, land vehicles, navigations then weapon control, then early warning radars which are; that means, even from a 5,000 kilometer if something is coming some missile is coming or some spacecraft is coming it can get detected. Also, you see that airborne things they require stealth technology. So, that is also part of the radar technology that how to make one invisible to a radar, how to design your aircraft your missile so that it becomes stealthy it does not get detected.

So, these are mainly all defense application but after 80s when this cold war etcetera ended lot of radar people they started research on the civilian applications. So, civilian application one of the civilian application you always see that if you go to any airport there is an airport traffic control where something is moving. So, always the aircrafts which are flowing for our now normal flights etcetera. So, they need a traffic control for there it is called ATC. So, air traffic control in airports, then in bad weather you see still, but nowadays the aircrafts they get landed, in heavy rains, in very darkness in night they fly, so all this is due to this radar.

Then in if there is a bad weather, there is a storm, there is a hailstorm, in that also, so where radar can detect whether there is a dangerous storm, then surveying over very large distance that whether there is something some anything submerged etcetera, then tornado detection, hurricane detection. Also, you see that in highways if a vehicle speeds up then police radars, they find out that, your speed was more. So, that is also a very good police application of radar.

In scientific application you see that precisely people are now sending various spacecraft etcetera landing on Mars, landing on moon, with very precise positions exactly in which crater they will land. So, all this is because of space vehicle guidance, satellite guidance then exploration of interplanetary space, extraterrestrial life finding also in archaeology whether there is a next site which I have archaeological importance; so, for that town planning, then to see when in radio astronomy radar astronomy. So, what is that how to find out black hole detection of black hole, detection of radio stars, even detection that is there any cancerous cells in the body breast cancer detection. So, all possible cancers are not there because the organs are inside the body, but in case of breast it is protruded. So, that can be easily detected by this radar technology.

Now, it also has lot of industrial application. Suppose, in railway whether there is anything in front of you, so collision avoidance radar. In automobile industry it is now self driven cars, so they fully rely on radar to navigate. Then in industry the cranes, heavy cranes if they misses the position there will be huge catastrophe, so control of cranes. Then industrial products, their profile measurement, then mining for mining exactly where to mine for that also radar is used.

Geological exploration, various geological layers their characterization, then in agricultures half surface water, then locust warning. Even behind a wall what is there, so that is called true all imaging radar, then sea through radar it can see through eyes, it can see through foliage etcetera. So, lot of applications nowadays you see drones etcetera, so they also require always for their navigation etcetera radars. So, it is an technology which is fully encompassing our daily lives more and more days it will encompass everything. So, it is a very good technology, I think will now unravel what is there inside the technology from the next class onwards.

Thank you.