

The following was presented to the YCARS on May 22 of 2003 for the technical program evening discussion.

The information presented comes from several sources – including the Internet, the Rad Lab books from MIT, text books, personal experience, and so forth.

It is intended strictly for entertainment only and is in no way a complete description of how radar works – that would take many many many more pages.

The intent is to give a flavor for how this fairly old technology was developed and works.

Enjoy!

Dave
WB4OZU
Rock Hill, SC

Fundamentals of Radar

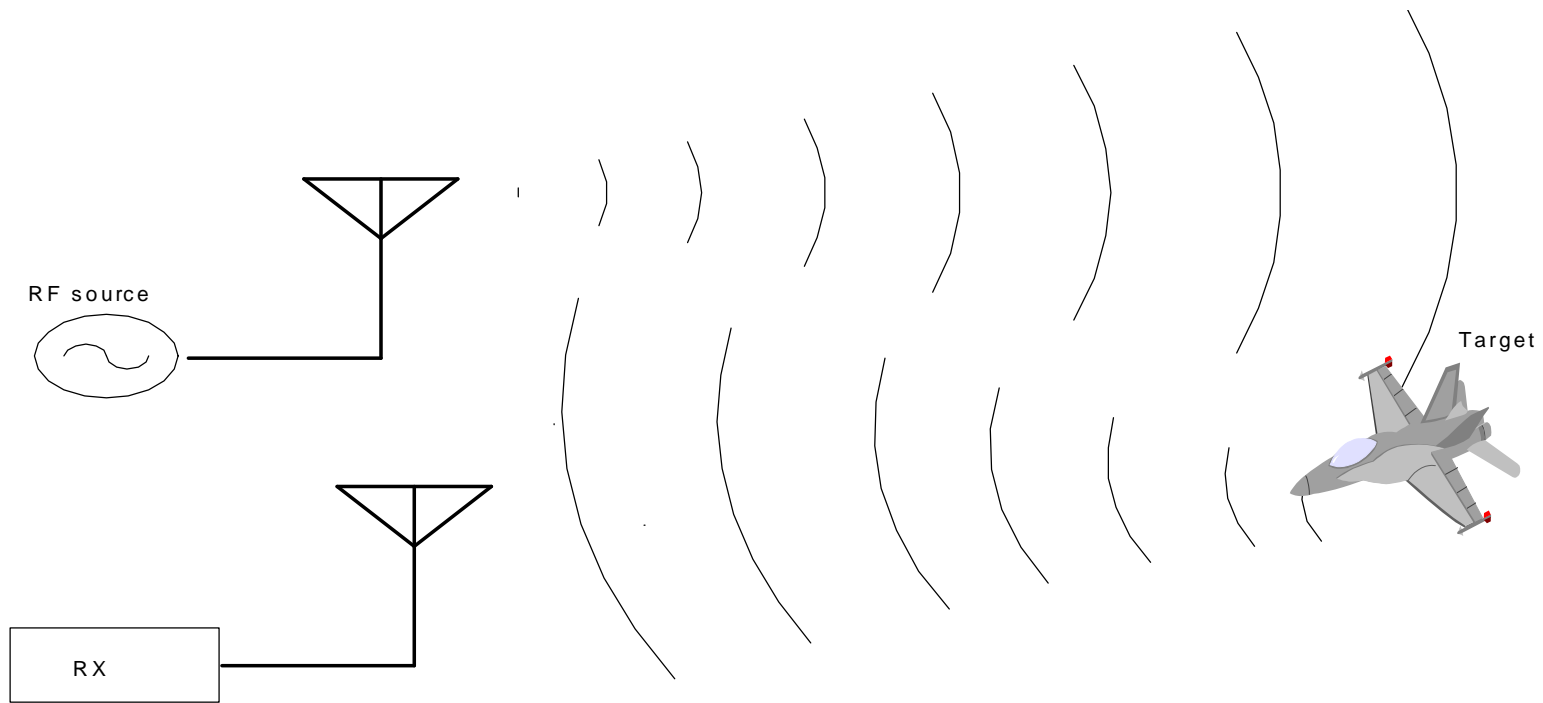
By WB4OZU

Definition: RADAR

RAdio Detection And Ranging.

- Detection in that reflected RF energy is recovered from an initiated source thereby detecting the target.
- Ranging from measuring the time the reflected energy takes to return. $\frac{1}{2}$ of the time to detect the reflection divided into the known velocity of the energy gives the distance to the target.
- Target is any intended illuminated object.

Ok, great definitions, but how does it work.

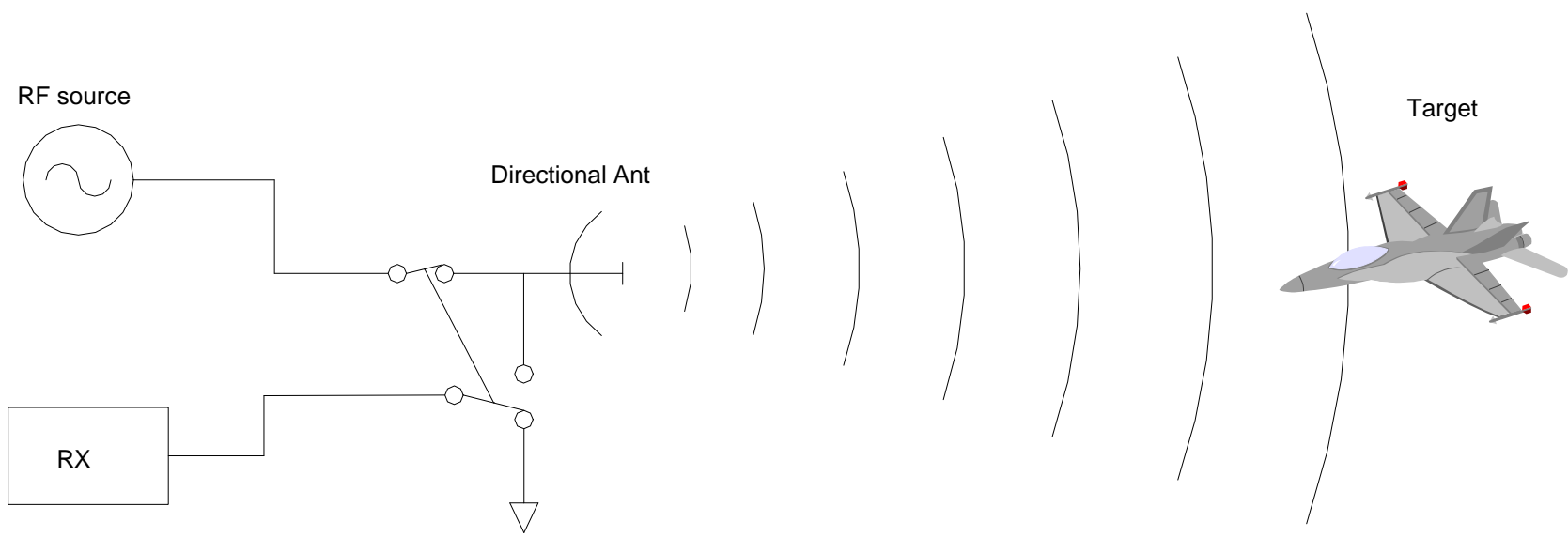


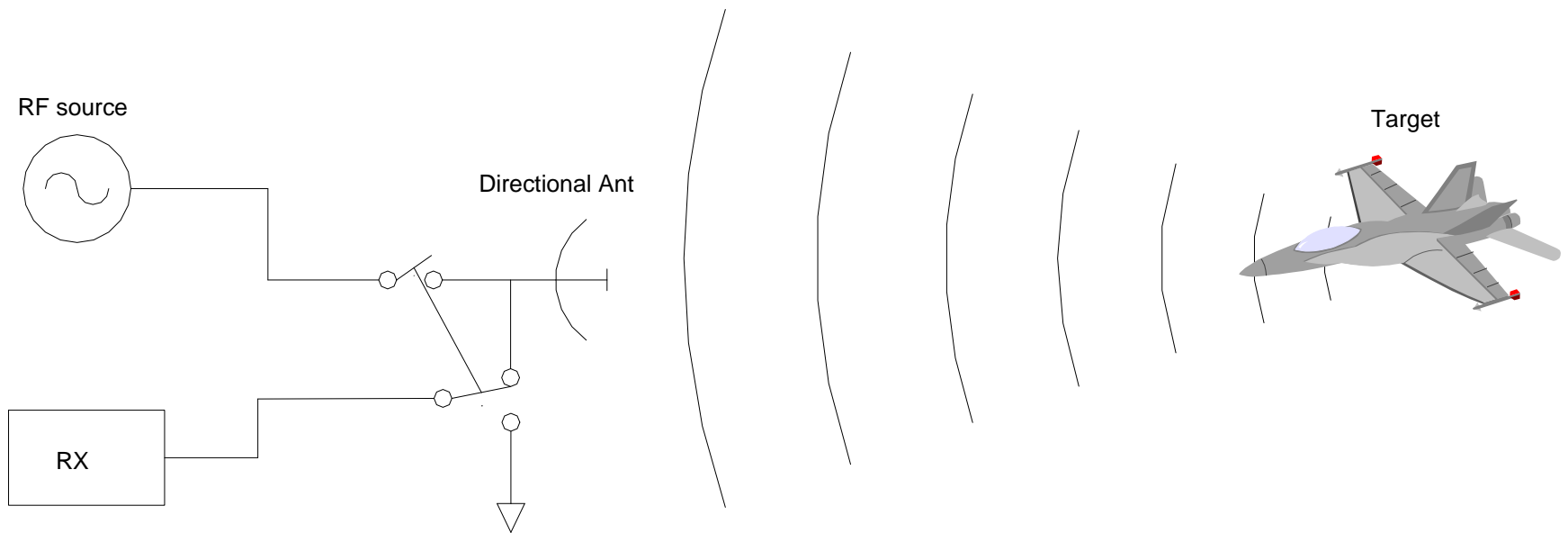
Problems

- Non directional antenna radiation swamps out Rx.
- Even directional still leaks enough to swamp out Rx.

Solution

- Turn Rx. off during Transmission.
- When? Pulse TX, only turn Rx. on when expect “echo.”

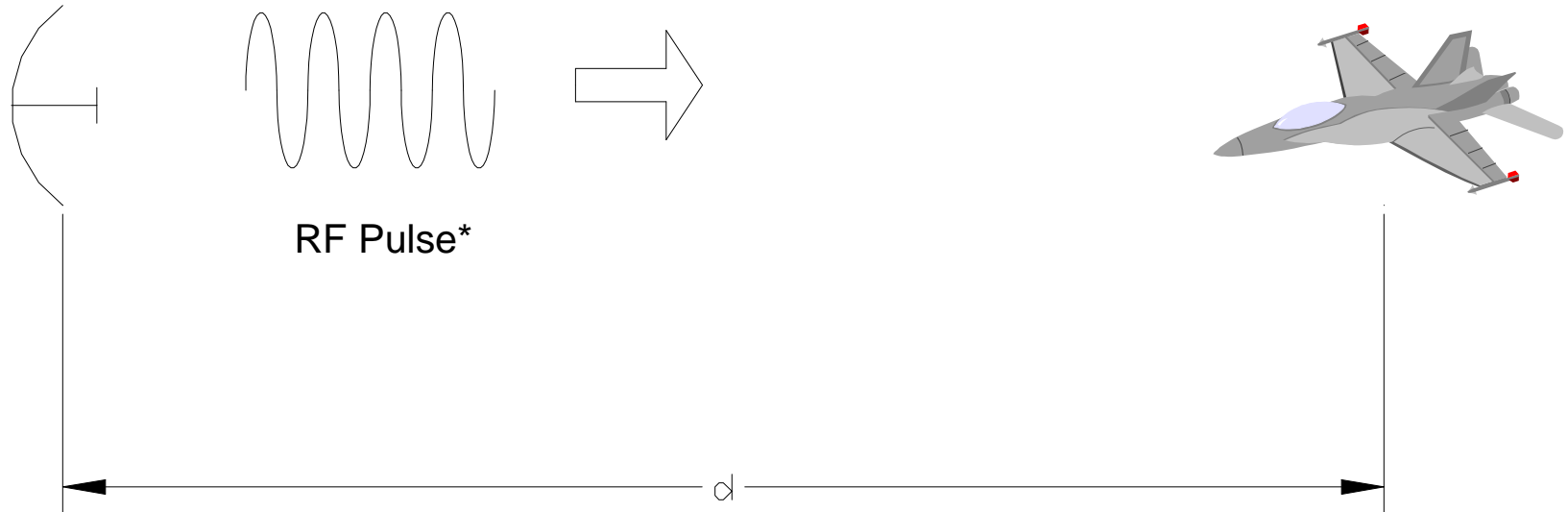




OK – We are now “detecting” a target using RF. What about ranging?

Target

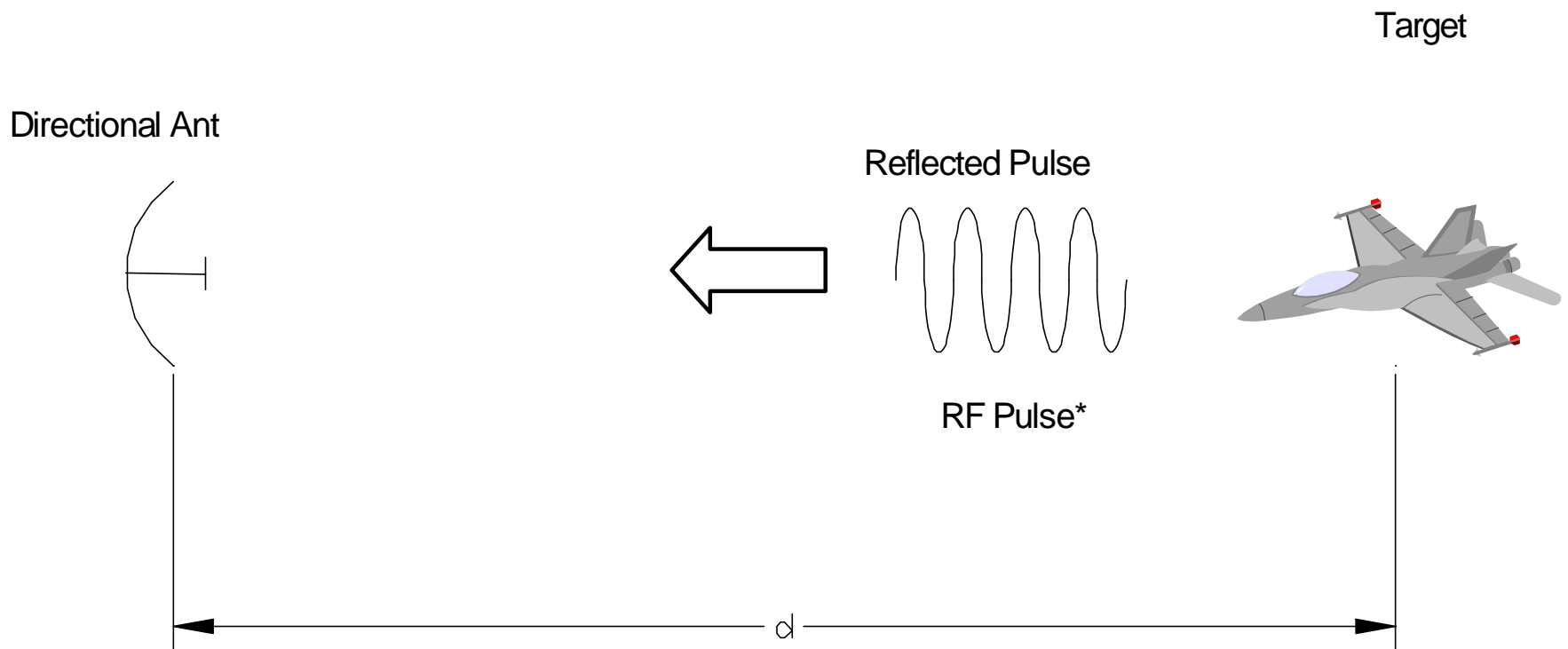
Directional Ant



Distance = Speed X time Speed = SOL (Speed of light for all intensive purposes) 100 km/s or 186 kmi/s

Time = μ , n, p seconds.

*Pulse could only be 4 cycles!



Distance echo must travel is $2d$, so actual “range” is

$$d = \frac{(\text{time to detect echo})(SOL)}{2}$$

So far a target (clouds, airplane, asteroid, missile) 150 miles away

$$150 \text{ miles} = T_D / 2 (186,000 \text{ mi/s})$$

$$T_D = 300 \text{ mi} / 186,000 \text{ mi/s}$$

$$= 300 / 186,000 \text{ s}$$

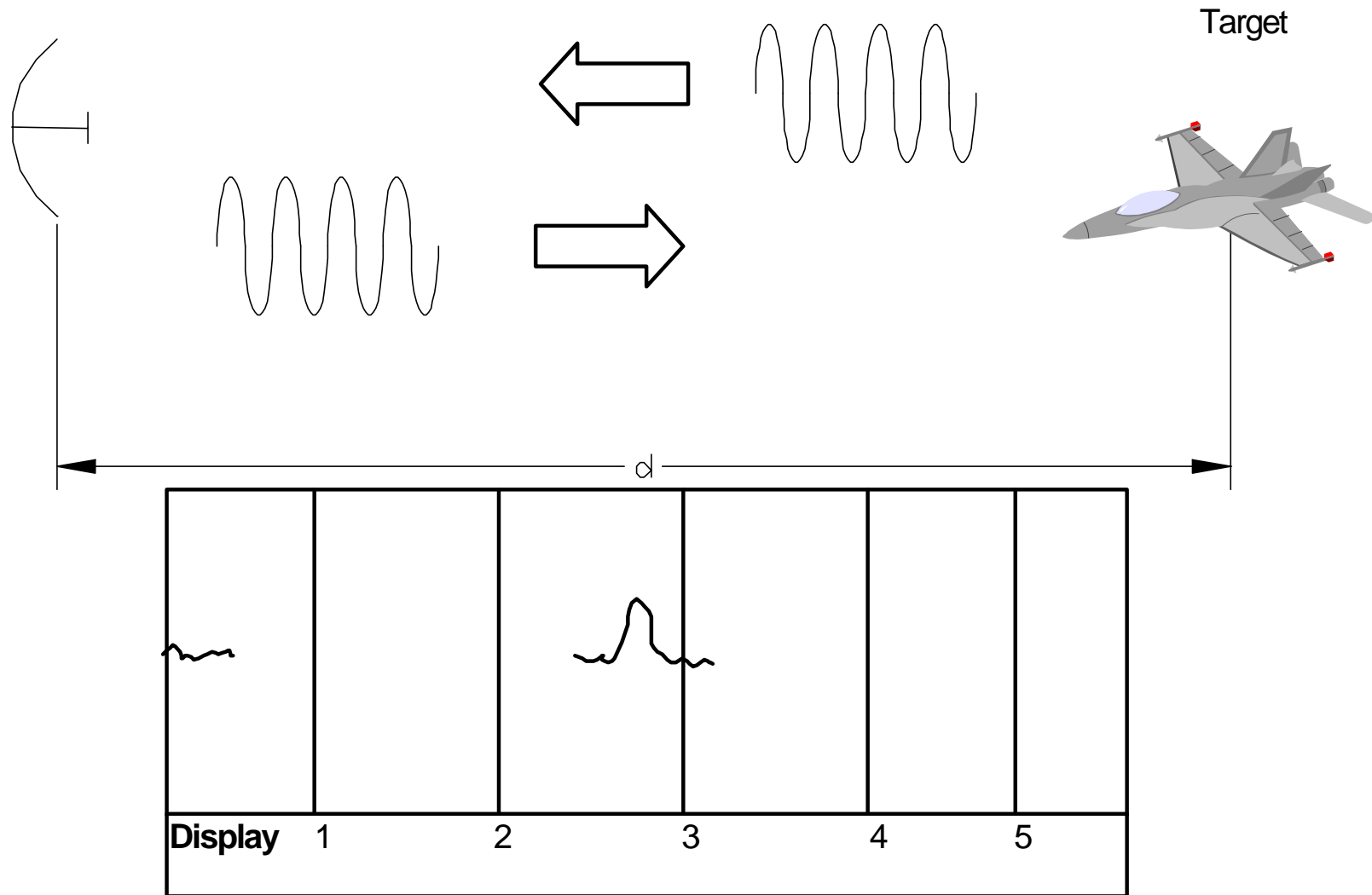
$$= 3 / 1860 \text{ s}$$

or **1.6 ms**

You would expect an echo back in 1.6 milliseconds.

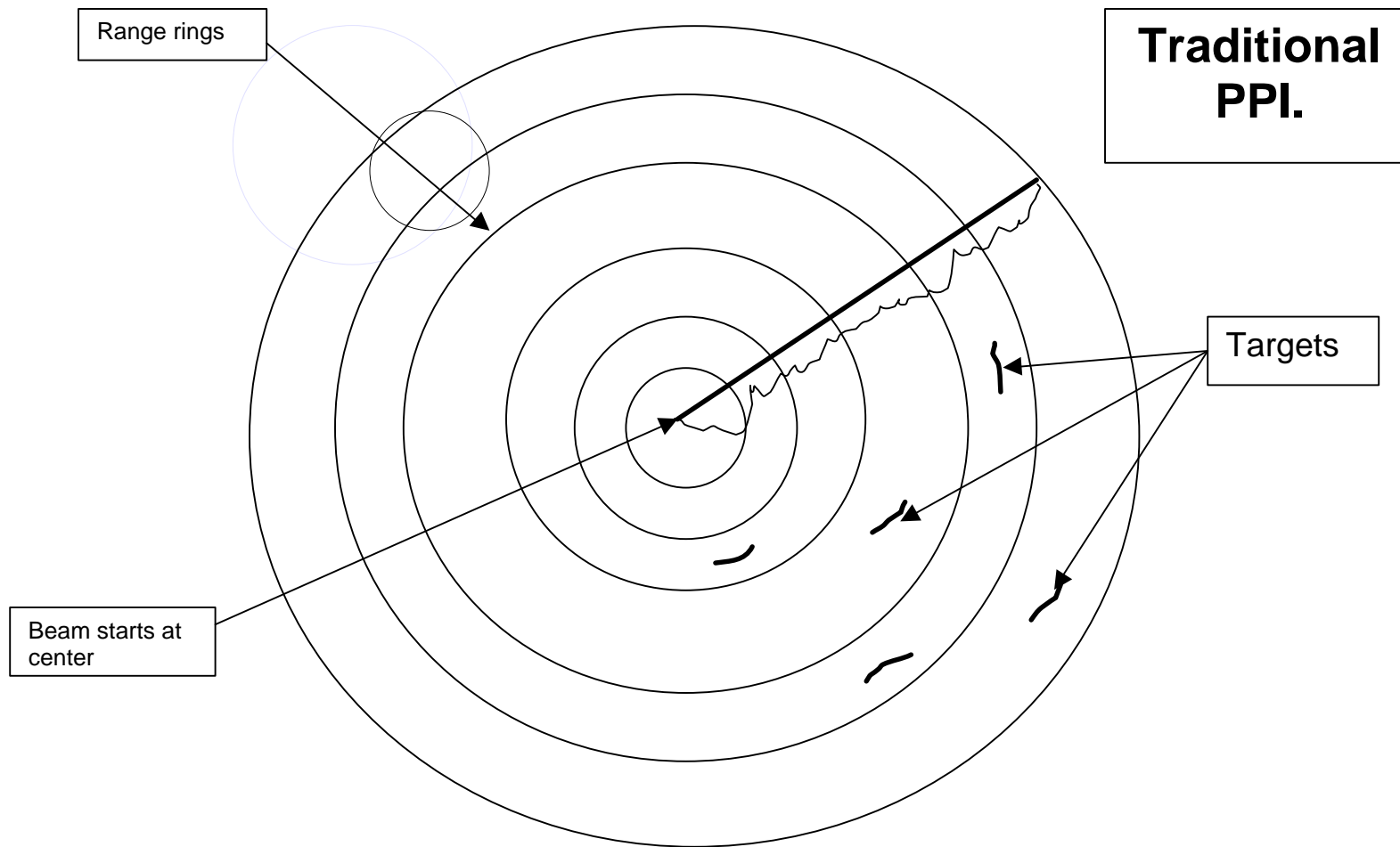
How to actually “range” target.

Use PPI or plan position indication in the vernacular. It's no more than a CRT with the electron beam sweeping from a position designating the antenna array and having the RF tied to the intensity control such that an echo gives a mark on the screen proportional to the return energy. Then the range is read on an overlaid scale like an Oscilloscope.



OK great, we have the range – only if the target is in alignment with the beam from the directional antenna. What if it moves off the axis?

- We need Azimuth indication, some way to rotate the beam – well, rotate the beam how?
- Rotate the whole set up – impractical.
- Rotate the antenna – OK, use a rotary joint, another art into itself.
- So, the Transmit/Receive antenna rotates, panning the compass with energy. How do we display it?
- Originally the same way - the beam deflection device on the neck of the CRT display ROTATED in sync with the antenna, thusly giving accurate azimuth indication.

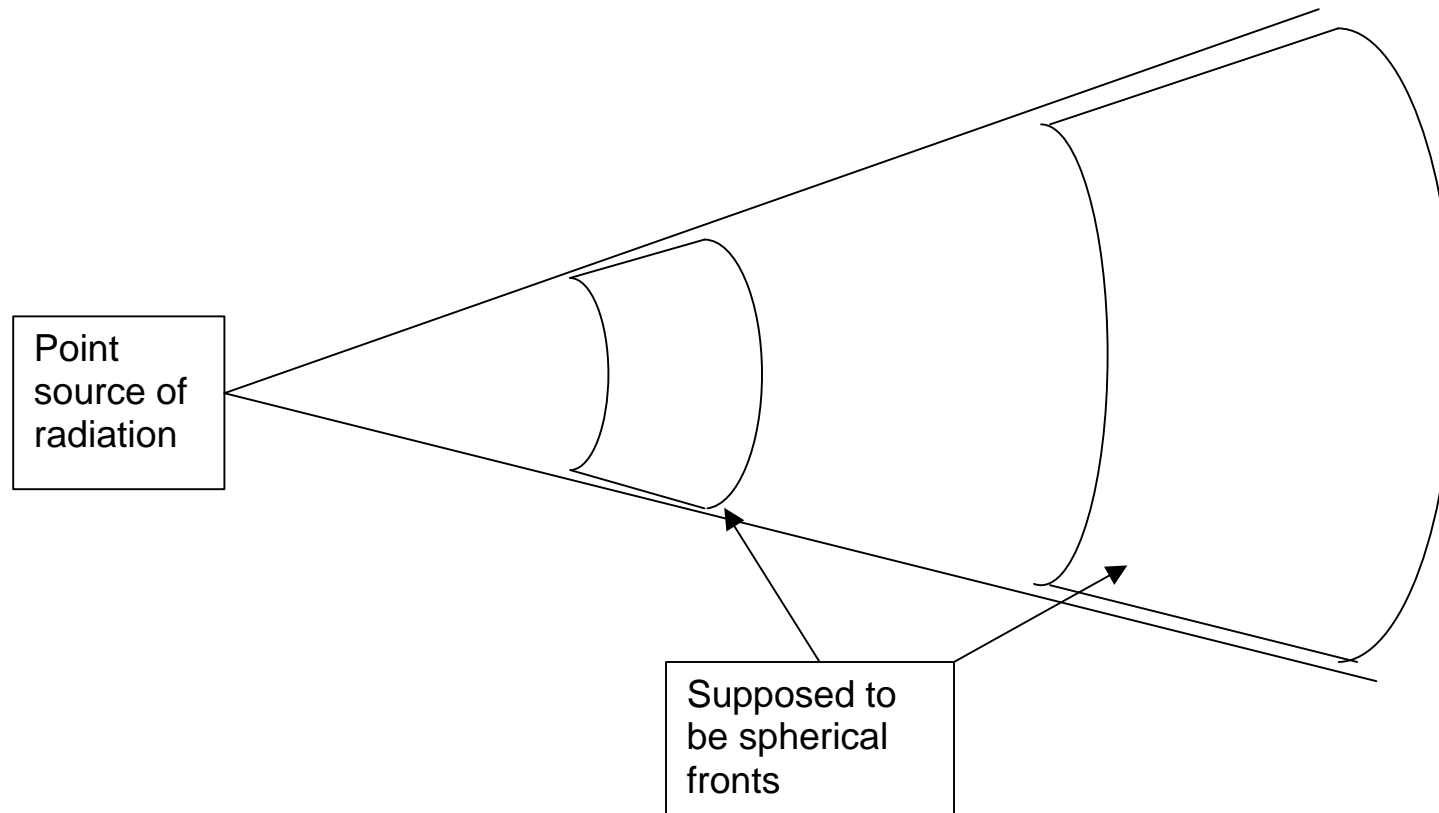


Deflection yoke like in TV is rotating behind front panel.

Alrighty, we've got the detection and ranging licked - or do we?

The range equation:

Energy from a source radiates on a spherical front



As the radiating sphere gets bigger, the same amount of energy that is on that surface is spread over a greater area, so the energy per unit area is decreasing as the sphere gets larger or further from the source.

The power density on the sphere can be mathematically related by:

$$P_{\text{rad}} = P_{\text{T}} / (4\pi R^2) \quad \text{where } P_{\text{rad}} \text{ is the power at a point whose distance from the source is } R \text{ (radius).}$$

So as the radius of the sphere gets bigger, the power at a point on that sphere gets smaller and smaller by the inverse radius squared.

So far every unit distance away you move from the source, the relative power compared to the transmitted decrease by $1/(\text{distance})^2$.

No wonder you need a big antenna for those weak signals!

But wait, it gets worse. We are looking for a reflected signal, so the reflected energy is:

$$P_{\text{rfl}} = (\sigma/4\pi R^2)(P_{\text{rad}}/4\pi R^2)$$

where σ is a measure of the reflectivity of the target (always less than 1)

So the energy we are looking for in our radar has diminished by $1/R^4$!

Note: This is why radar detectors (indeed any ECM) are effective. The circuit response signal is a $1/R^2$ power vs. a $1/R^4$ power for the radar gun.

Very nice. So we have a system that can tell us distance and direction, but we can't use it because the return energy is un-detectable.

What to do - What to do?

Make the Rx extremely sensitive for the power provided – Painful and impossible.

Jack the Transmission power way up. Ditto.

Well along came the Brits.

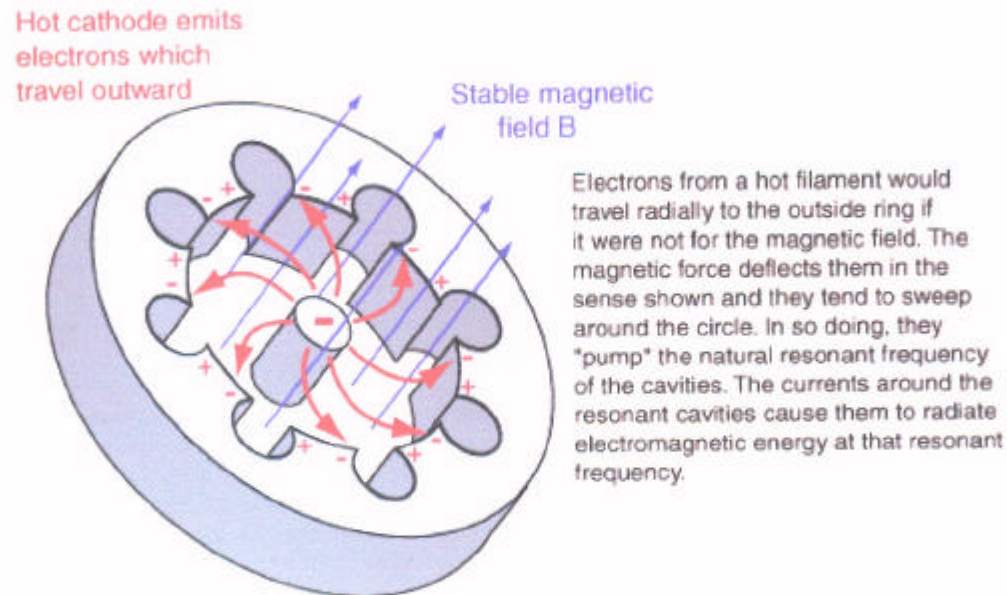
Early in WWII (late 30's actually) some rocket scientist in England came up with a way to make extremely high power, rather long duty cycle, stable, RF oscillators.

In fact, some tech folks thought reaching power levels desired was impossible, and it was with conventional technology.

Enter the Magnetron. That's right, the heart of every Microwave oven. What better way to beat swords into plowshares?

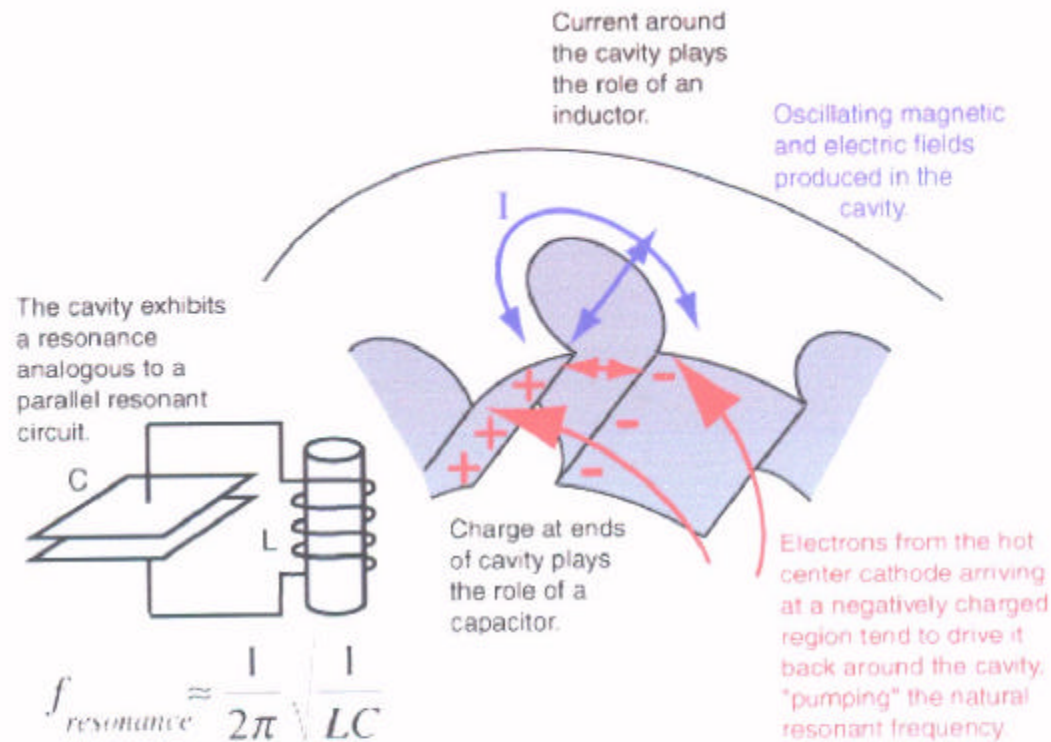
The Magnetron

The [microwave radiation](#) of microwave ovens and some radar applications is produced by a device called a magnetron.



The magnetron is called a "crossed-field" device in the industry because both [magnetic](#) and [electric](#) fields are employed in its operation, and they are produced in perpendicular directions so that they cross. The applied magnetic field is constant and applied along the axis of the circular device illustrated. The power to the device is applied to the center cathode which is heated to supply energetic electrons which would, in the absence of the magnetic field, tend to move radially outward to the ring anode which surrounds it.

Magnetron Circuit



Electrons are released at the center hot cathode by the process of thermionic emission and have an accelerating field which moves them outward toward the anode. The axial magnetic field exerts a [magnetic force](#) on these charges which is perpendicular to their initially radial motion, and they tend to be swept around the circle. In this way, work is done on the charges and therefore energy from the power supply is given to them. As these electrons sweep toward a point where there is excess negative charge, that charge tends to be pushed back around the cavity, imparting energy to the oscillation at the natural frequency of the cavity. This driven oscillation of the charges around the cavities leads to radiation of electromagnetic waves, the output of the magnetron.

Magnetron is a cross-field device so called because both electron and magnetic field are used. How?

First you need a circulating cloud of electrons. OK, how? Finally another use for the right hand rule. Give a thumbs up sign. The thumb indicates the magnetic field orientation. The fingers indicate the electron field rotation (yes, there is movement)

Looking at the magnetron cross (ha-ha) section, if an electron source (a red-hot filament configured as a cathode) is in axial position with the center of the cylinder, and a **STRONG** magnetic field is applied axially also, assuming it is in a high vacuum, what happens?

Electrons boil off the cathode (like in every vacuum tube there ever was). In the presence of a magnetic field, they will rotate, according to the RHR.

On the ID of the cylinder are a series of circular grooves in line with the magnetic field lines. Due to biasing on the anode, the rotating electron cloud sweeps past each opening, inducing RF energy into each cavity structure, based on the physical construction of each cavity, analogous to blowing across the top of a “pop” bottle. Depending on how much liquid is in the bottle, the resonance frequency changes.

So, we have a circulating E field past tuned cavities, effectively inducting oscillating charges in the cavities. A pickup is placed in a cavity and this huge narrow band resonance RF energy is coupled out.

When this device was demonstrated, it was deemed so important to the WWII effort, it was secretly sent to America to be incorporated in the radar development program away from potential destruction or capture.