RADAR?

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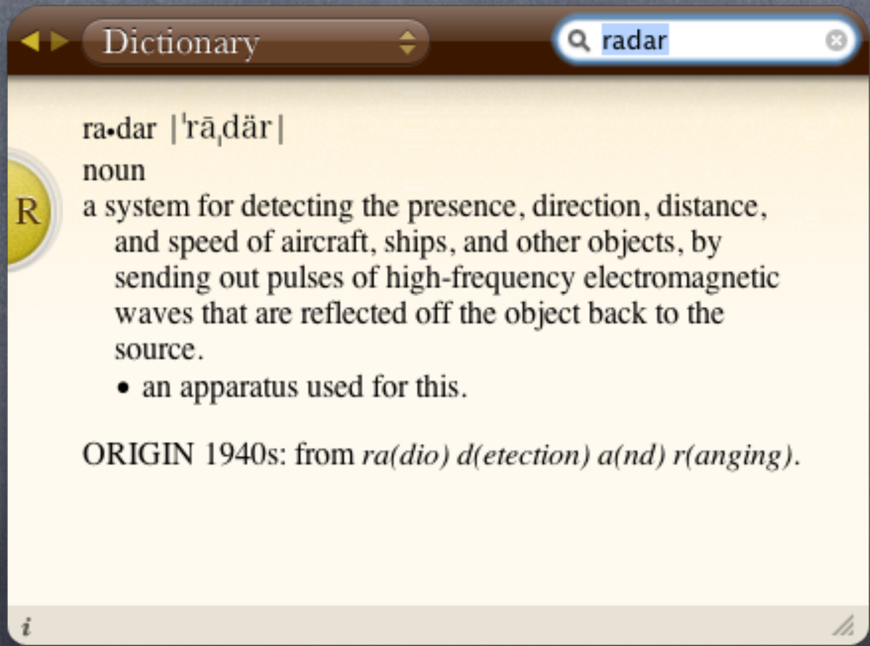
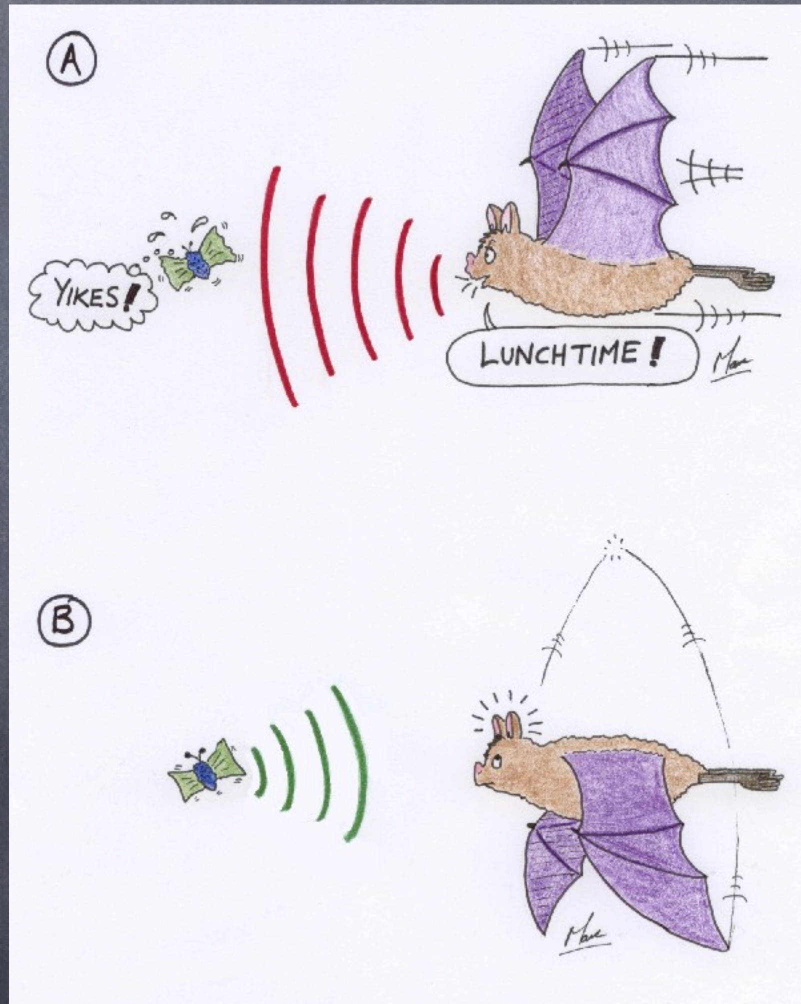
Radio Detection And Ranging

RADAR


Dictionary
radar
ra•dar |ˈrāˌdär|
noun
a system for detecting the presence, direction, distance, and speed of aircraft, ships, and other objects, by sending out pulses of high-frequency electromagnetic waves that are reflected off the object back to the source.
• an apparatus used for this.
ORIGIN 1940s: from *ra(dio) d(etection) a(nd) r(anging)*.

Nature's done it already



Hans Christian Ørsted

On 21st April 1820,
Ørsted discovered a direct relationship between electricity and magnetism, which prompted much research into electrodynamics.

(14 August 1777 – 9 March 1851)

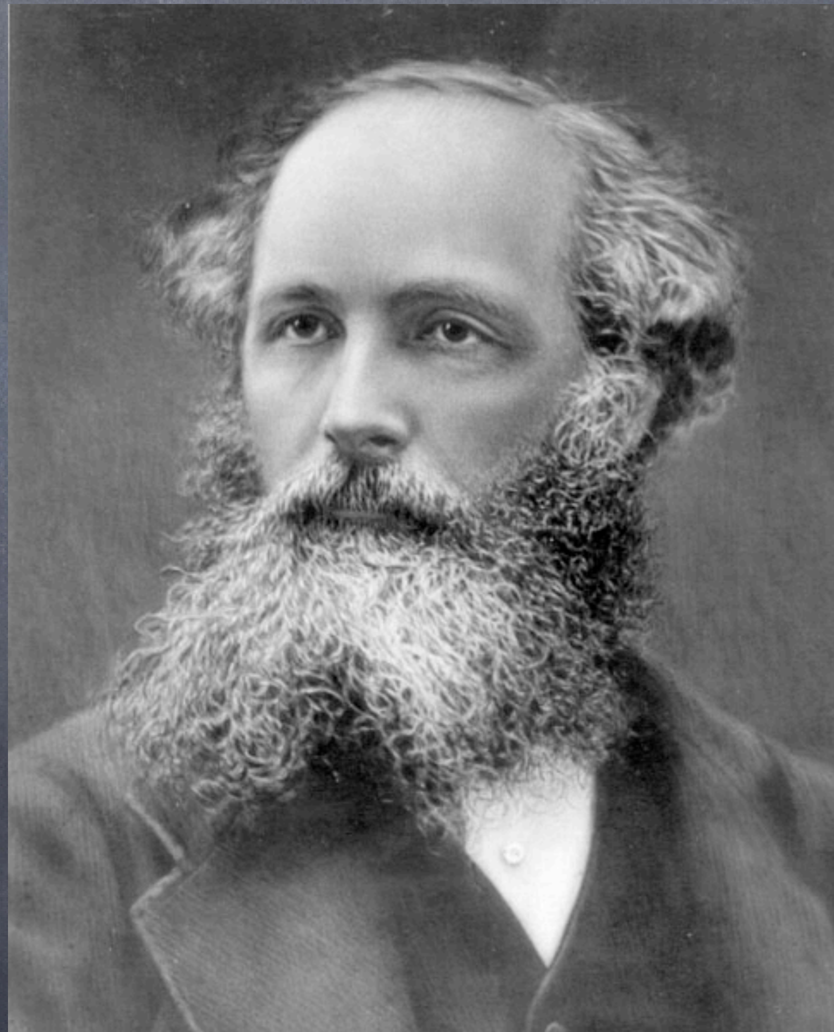
André-Marie Ampère

Inspired by Ørsteds discovery, Ampère developed a mathematical theory describing electromagnetic phenomena and predicting many new ones.

(20th January 1775 - 10th June 1836)

James Clerk Maxwell

The Maxwell Equations showed that electricity and magnetism are two aspects of the same force.



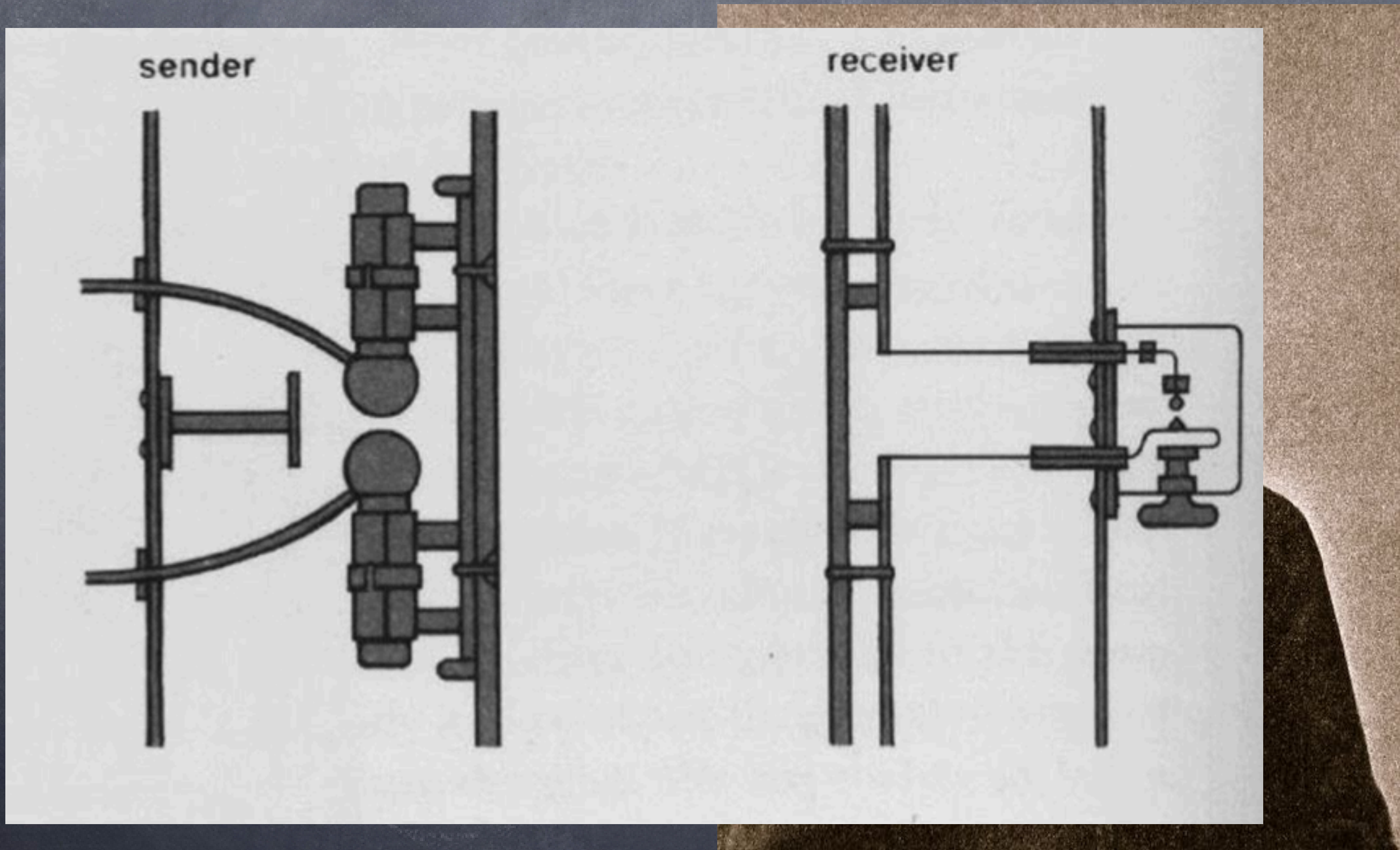
(13 June 1831 – 5 November 1879)

Heinrich Rudolf Hertz

Hertz proved that electricity can be transmitted by electromagnetic waves.

(22 February 1857 – 1 January 1894)

Heinrich Rudolf Hertz



(22 February 1857 – 1 January 1894)

Guglielmo Marconi

Inventor of the radio telegraph system; first transatlantic radio transmission on 12 December 1901 at 820 kHz.

(25 April 1874 - 20 July 1937)

Ionised Layer

Oliver Heaviside

(18 May 1850 - 3 February 1925)

Arthur E Kennelly

(17 December 1861 - 18 June 1939)

In 1902, Heaviside and Kennelly independently predicted an ionised layer in the upper atmosphere that would reflect radio waves.

Edward Appleton

Appleton and his colleagues were one of two teams to prove the existence of a reflecting layer at a height of about 100 km (E layer), soon followed by the discovery of the F layer at around 250 km.

(6 September 1892 – 21 April 1965)

Ionosonde

G Breit and M A Tuve, A radio method of estimating the height of the conducting layer, Nature, 116, p. 357, 1925.

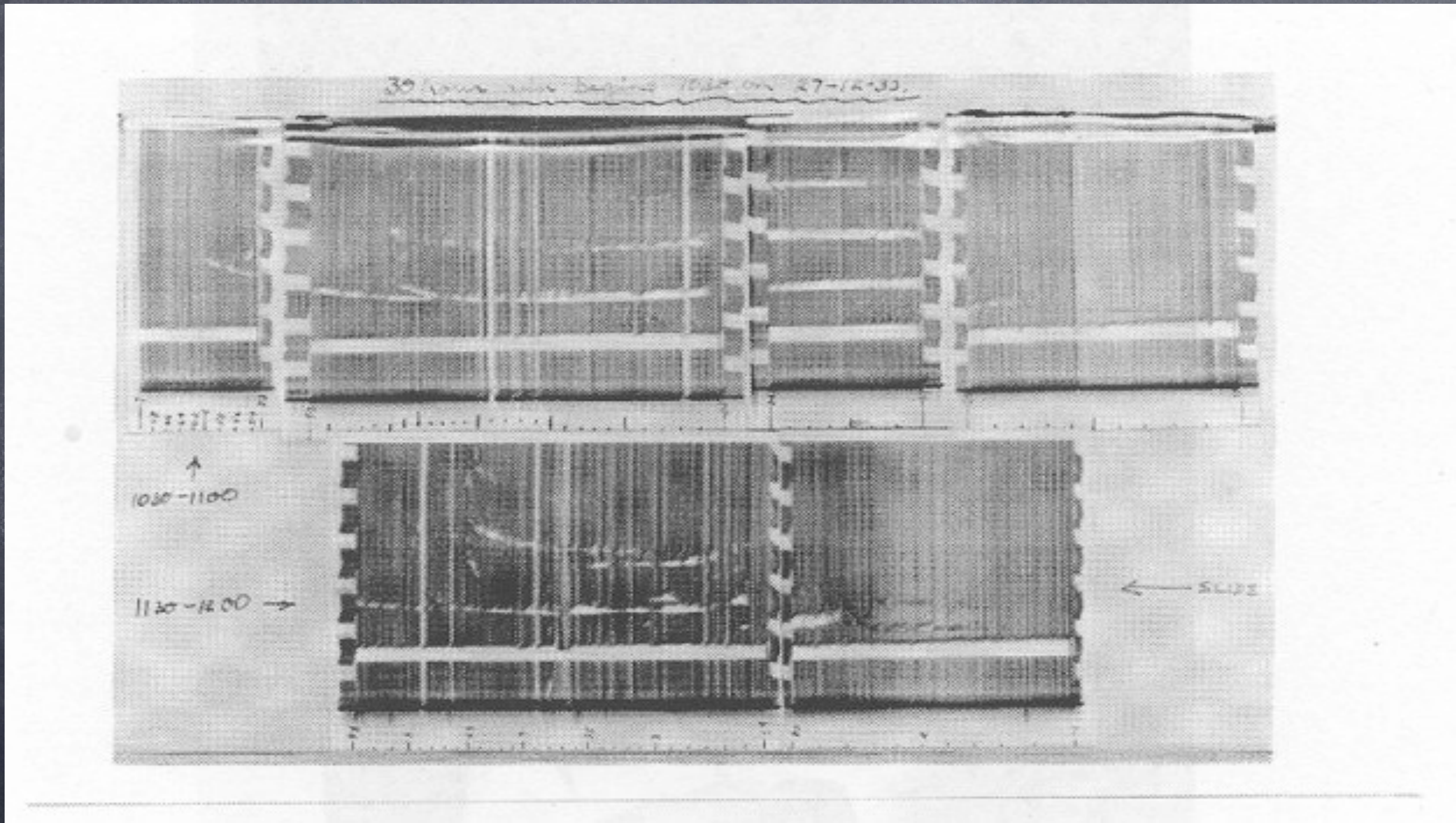
Gregory Breit

(14 July 1899 - 11 September 1981)

Merle Tuve

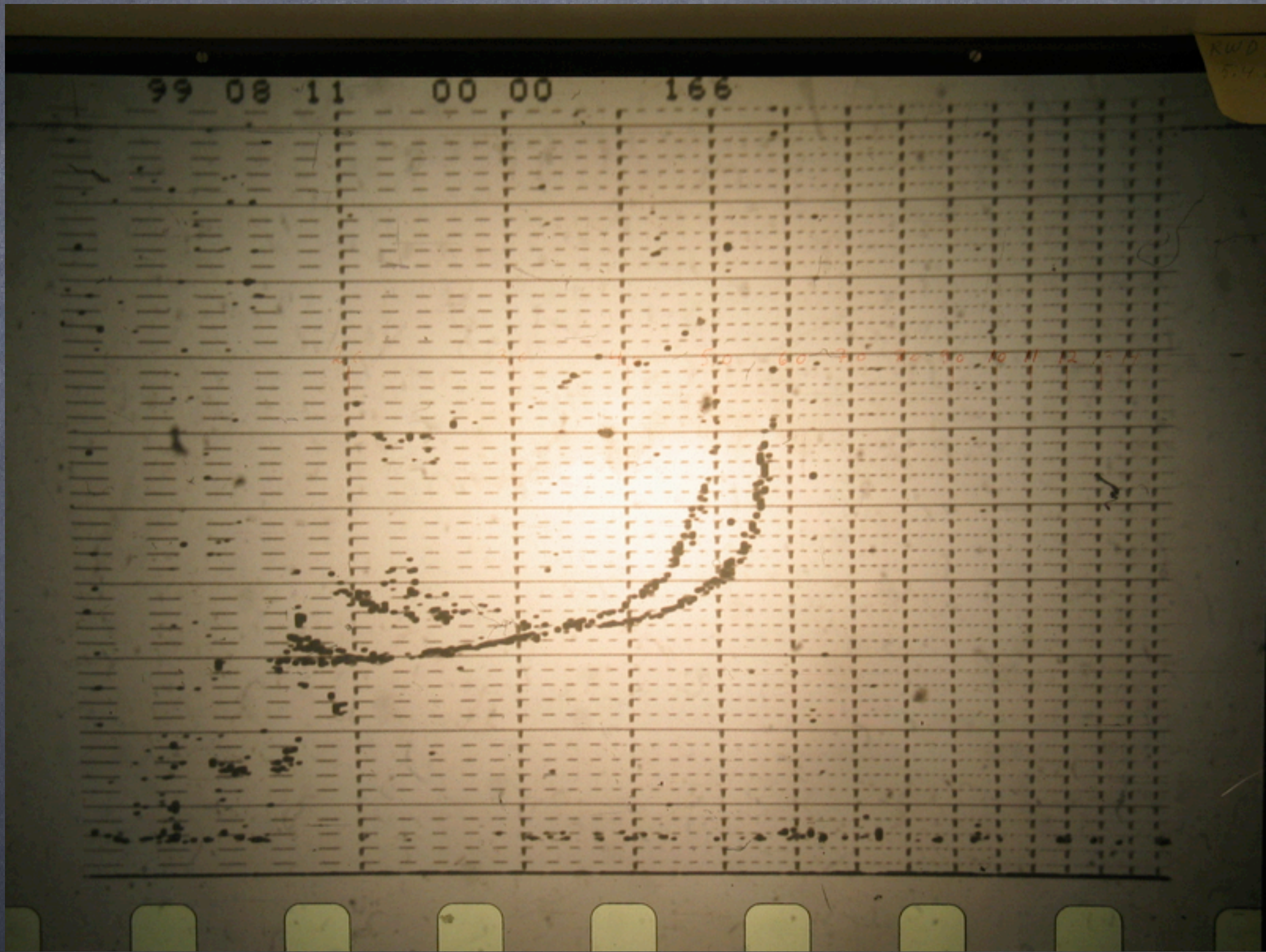
(27 June 1901 - 20 May 1982)

Regular Ionograms



Radio Research Station Slough, Buckinghamshire
27th December 1933, 10:30-11:00 UTC and 11:30-12:00 UTC.

Sodankylä Ionosonde



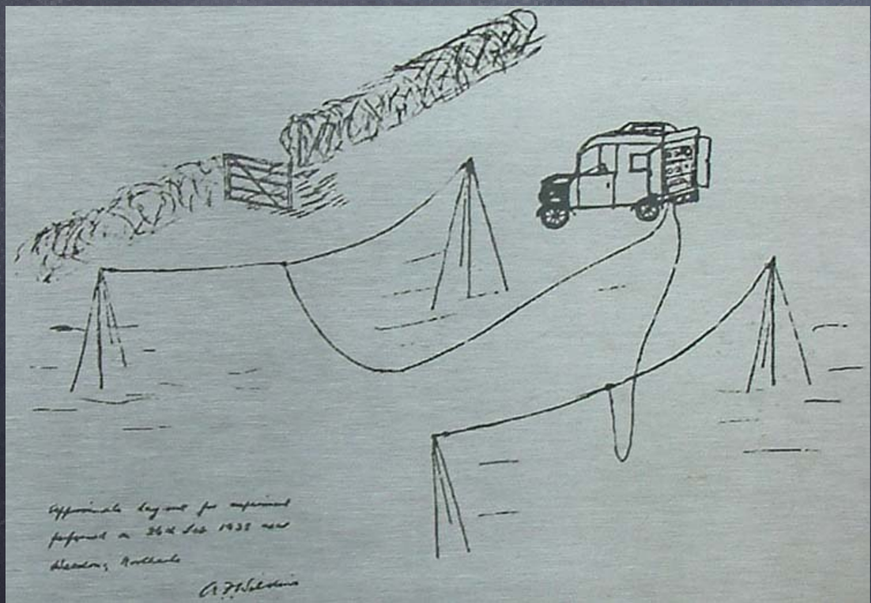
(1 August 1957 – 15 November 2005)

Detecting Aircraft

Denge, Dungeness, Kent, UK

Robert Watson-Watt

Daventry Experiment on 26 Feb. 1935; patent for RADAR on 2 Apr.; by June detecting aircraft at 27 km.



(13 April 1892 – 5 December 1973)

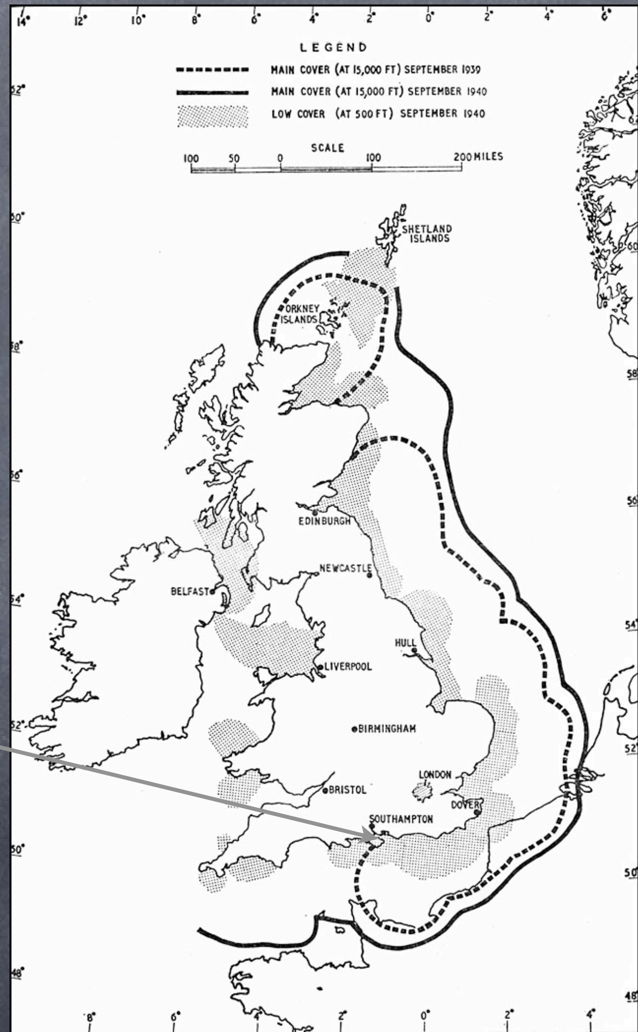
Chain Home

Ventnor, Isle of Wight

Multi-freq 12 m,

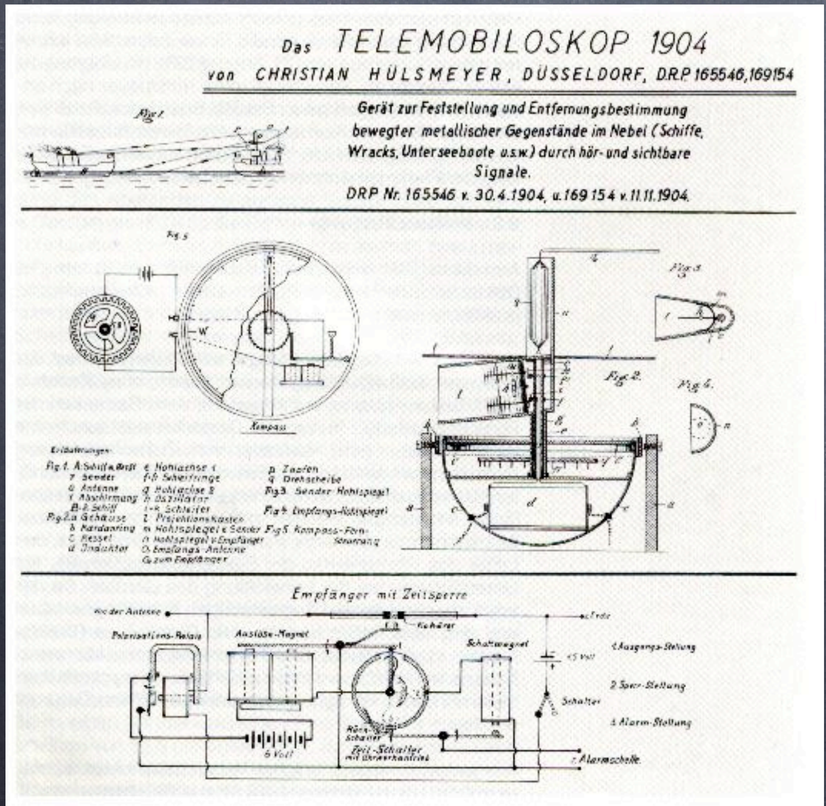
200 km range

CHlow 1.5 m



Christian Hülsmeyer

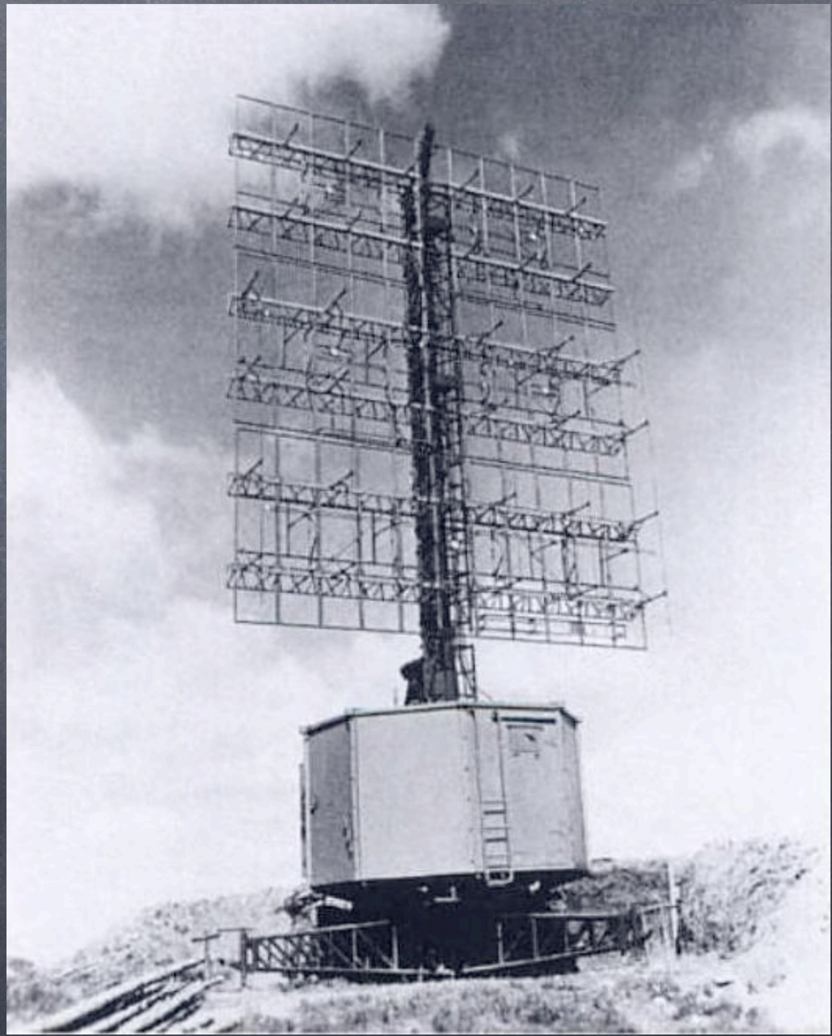
Invented RADAR …
… but no-one noticed.



(25 December 1881 - 31 January 1957)

Freya

- German radar op. 1938.
- Portable(ish).
- 120-130 MHz (2.5-2.3 m).
- PRF 500 Hz, 3 μs pulses.
- Rotates 360°, 160 km range.
- Countermeasures:
  - Moonshine: re-emit amplified pulses (8 a/c = 100 bombers).
  - Jamming: 9 a/c create a 200-mile (320 km) gap.



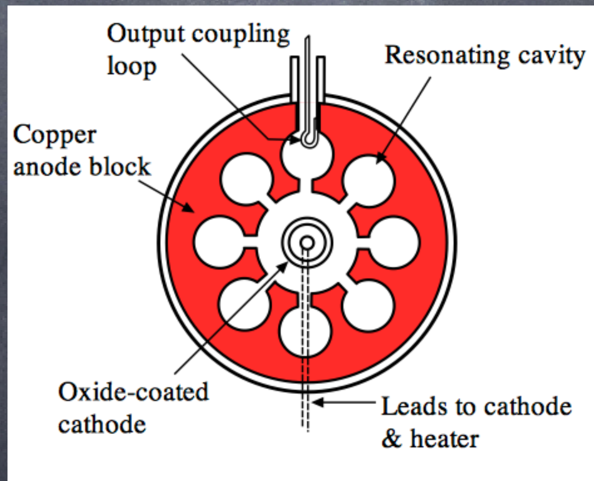
September 1939

More or less rudimentary but operational radars:

Britain, France, Germany, Hungary, Italy, Japan, the Netherlands, Russia, Switzerland, and the USA.

Cavity Magnetron

- Invented at U Birmingham, UK, by John Randall and Henry Boot.
- By mid-1940 cavity magnetron developed into a small, light-weight transmitter (3 GHz at 15kW).
- 10x improvement over other radar.



Resonant cavity magnetron high-power high-frequency oscillator

Status after WWII

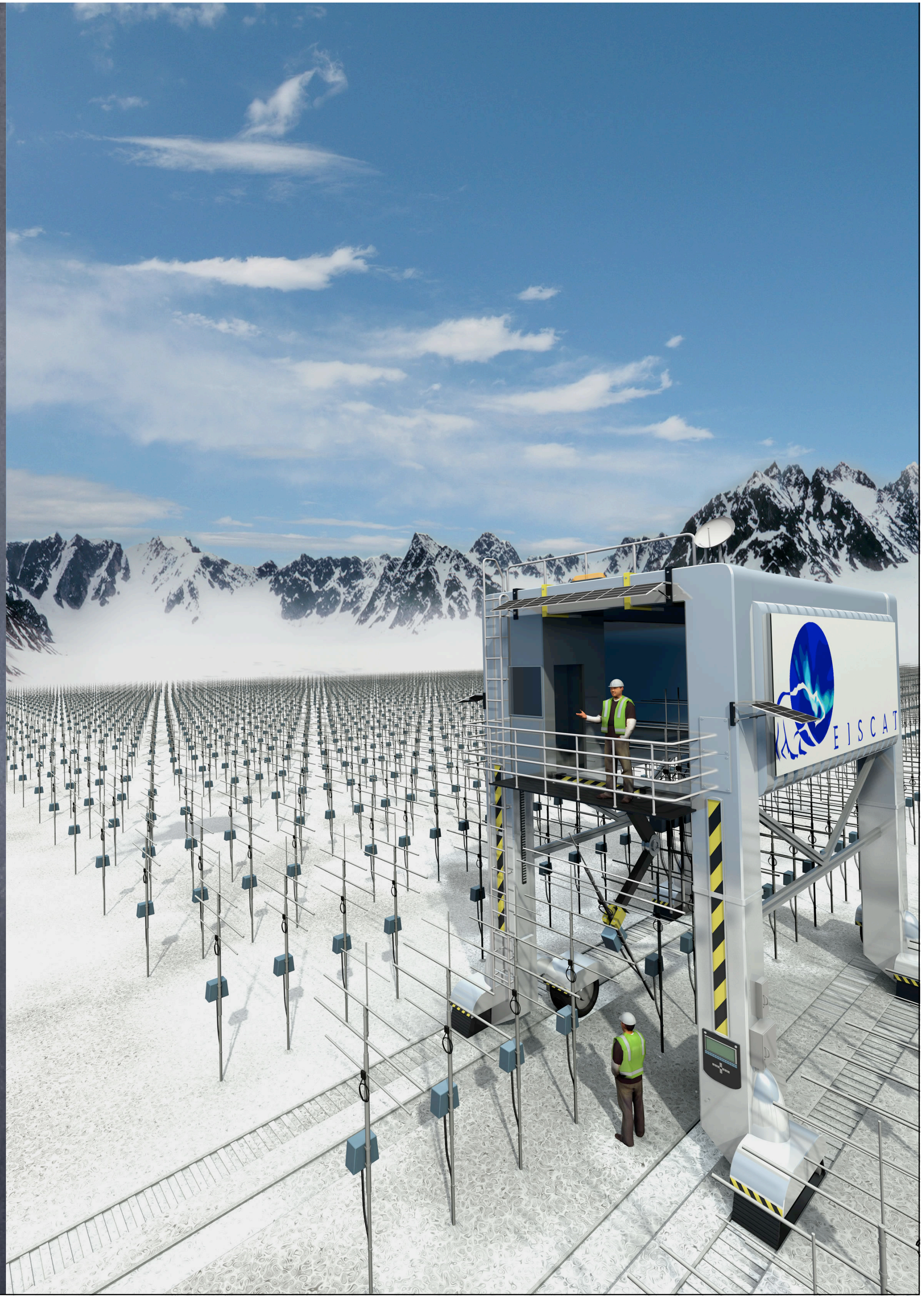
- RADAR had evolved from prototypes to a multitude of different systems.
- Microwave signal generation had become practical.
- Advances in aerials, transmitters, receivers, displays etc. led to wide-spread use in communications and radar applications.

… fast forward …

Does the Future of Incoherent Scatter look like this?

EISCAT_3D

Welcome aboard!



KAIRA

Kilpisjärvi Atmospheric Imaging Receiver Array

=> Juha Vierinen's talk on Thurday!

blog: kaira.sgo.fi

30-300 GHz / 10-1 mm	EHF	microwave radio relays	
3-30 GHz / 10-1 cm	SHF	satellite comm & nav, wireless LAN	weather radars
0.3-3 GHz / 1-0.1 m	UHF	cell phones, TV, microwave ovens	EISCAT UHF, ESR, AMISR
30-300 MHz / 10-1 m	VHF	FM radio, TV, HAM	EISCAT VHF, JRO, MST radars, meteor radars...
3-30 MHz / 100-10 m	HF	shortwave radio	Ionosondes, SuperDARN
0.3-3 MHz / 1-0.1 km	MF	AM radio	Ionosondes
30-300 kHz / 10-1 km	LF	radio beacons, submarine comm	AARDDVARK
3-30 kHz / 100-10 km	VLF	navigation	AARDDVARK
0.3-3 kHz / 1-0.1 Mm	ULF	audio signals on analogue telephone	
30-300 Hz / 10-1 Mm	SLF	electric grids	
3-30 Hz / 100-10 Mm	ELF	metal detectors	Earth-iono. waveguide, Schumann resonance

Type	Frequency	λ [m]	Power [kW]	Aperture [λ]	Height
MF Radar	MF-HF	150-50	0.01-1	1-10	M, LT, I
Ionosonde	HF	300-10	0.01-5	0.5-1	T, I
Coherent scatter rad	HF-VHF	30-1	0.1-1	5-50	T, I
Meteor radar	HF-VHF	10-6	0.1-10	2-10	M, LT
MST radar	VHF	6-7	1-100	5-50	M, S, T
Incoherent scatter rad	VHF-UHF	6-0.25	500-2000	100-300	M, LT, I
ST radar	UHF	6-0.1	1-500	10-500	S, T

T: Troposhere; S: Stratosphere; M: Mesosphere; (L)T: (lower) Thermosphere; I: Ionosphere

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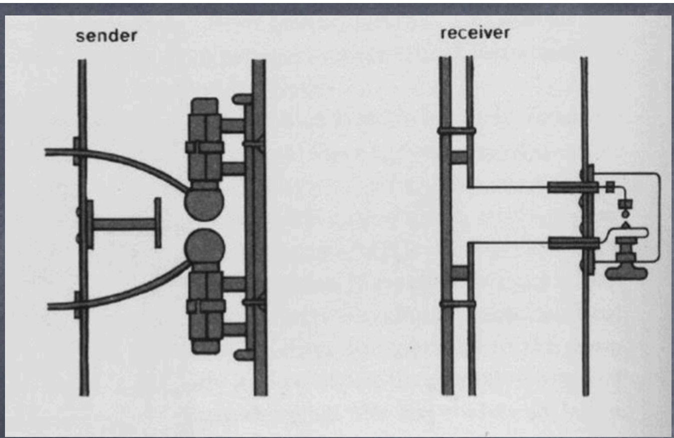
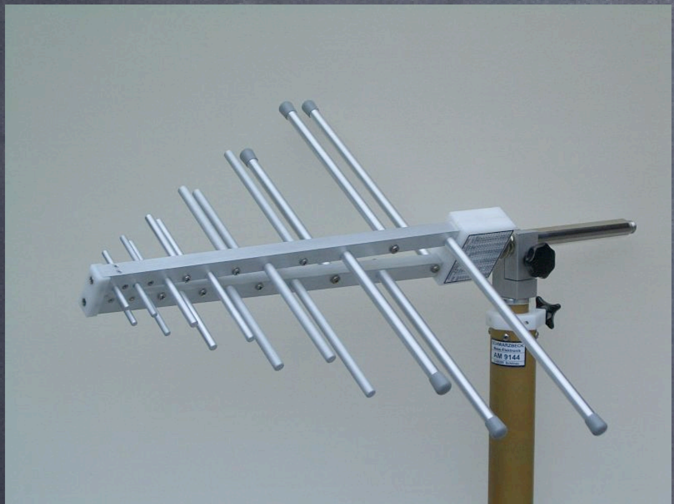
Incoherent scatter rad	VHF-UHF	6-0.25	500-2000	100-300	M, LT, I
ST radar	UHF	6-0.1	1-500	10-500	S, T

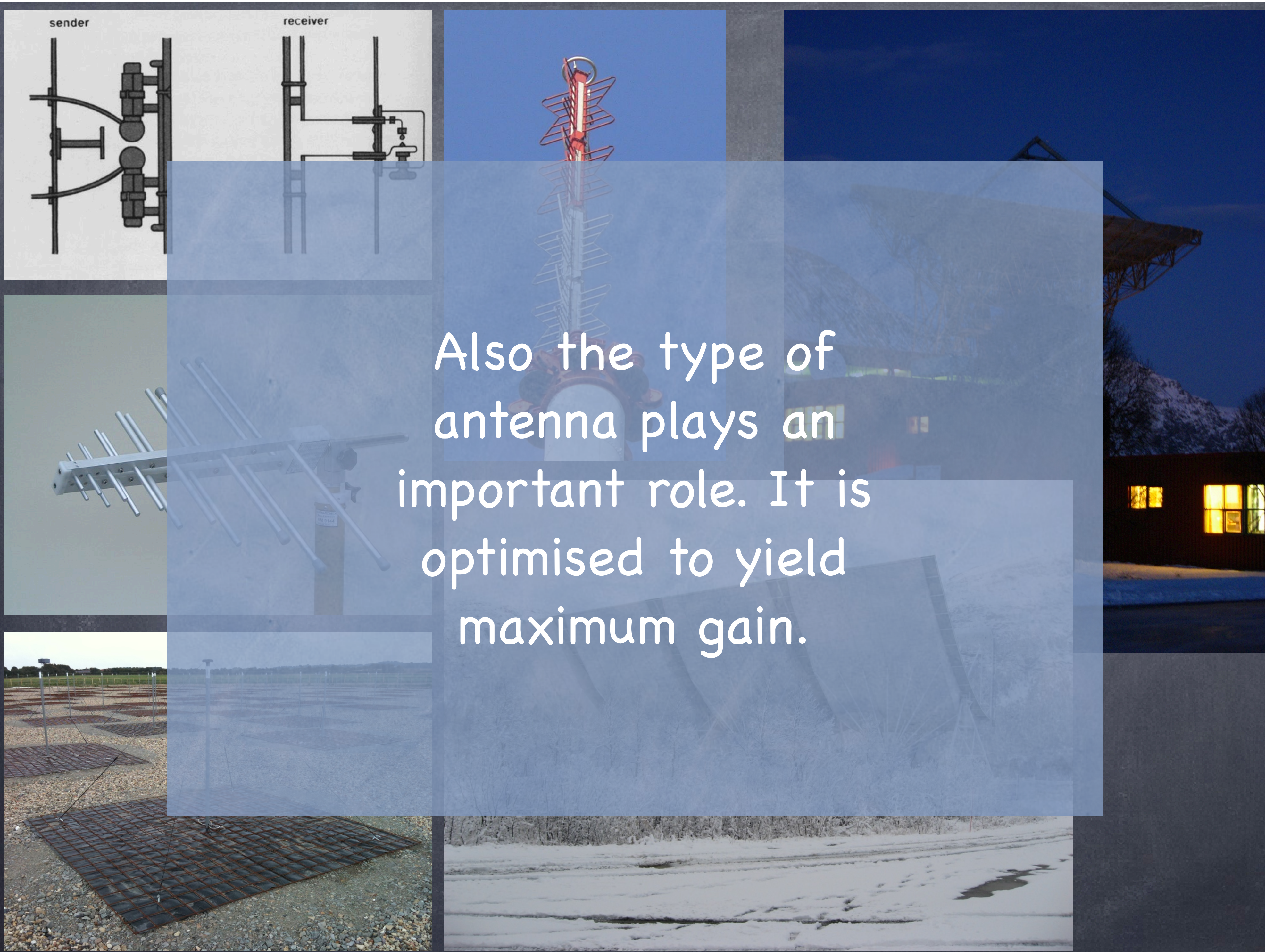
What you can observe is a function of frequency (wavelength), power and aperture!

Far-Field Condition

- Far-field of antenna: electromagnetic waves can be approxmated by plane waves.
- Energy distribution is well defined.
- Most atmospheric radars are designed to operate in the far-field, farther away than D_a^2/λ.
- EISCAT UHF: $(32\text{m})^2$ / 0.32m = 3200m
- MU radar: $(103\text{m})^2$ / 6.45m = 1600m

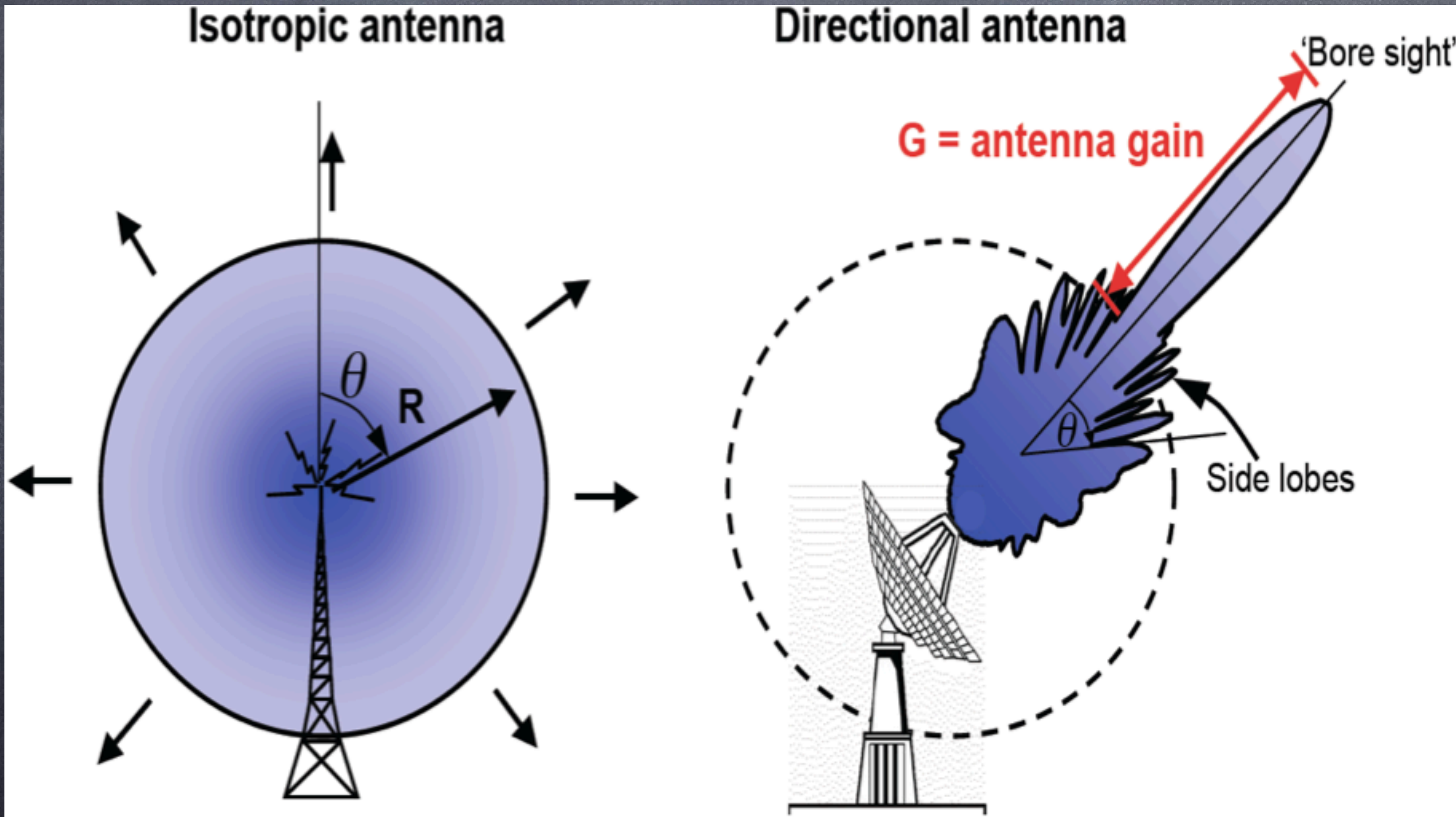

sender
receiver





Also the type of antenna plays an important role. It is optimised to yield maximum gain.

Radiation Patterns



Radar Equation

$$P_r = P_t \cdot \frac{4\pi A}{\lambda^2} \cdot \frac{1}{4\pi R^2} \cdot \frac{1}{L} \cdot \sigma \cdot \frac{1}{4\pi R^2} \cdot A$$

Received power

Radar Equation

$$P_r = P_t \cdot \frac{4\pi A}{\lambda^2} \cdot \frac{1}{4\pi R^2} \cdot \frac{1}{L} \cdot \sigma \cdot \frac{1}{4\pi R^2} \cdot A$$

Received power is equal to
- transmitted power ...

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Received power is equal to
- transmitted power times
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- backscatter cross section ...

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- transmitter gain times
- spread factor times
- any losses in the system times
- backscatter cross section times
- spread factor at point target ...

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Received power is equal to
- transmitted power times
- transmitter gain times
- spread factor times
- any losses in the system times
- backscatter cross section times
- spread factor at <u>point target</u> times
- receiver aperture.

Hard vs Soft Target

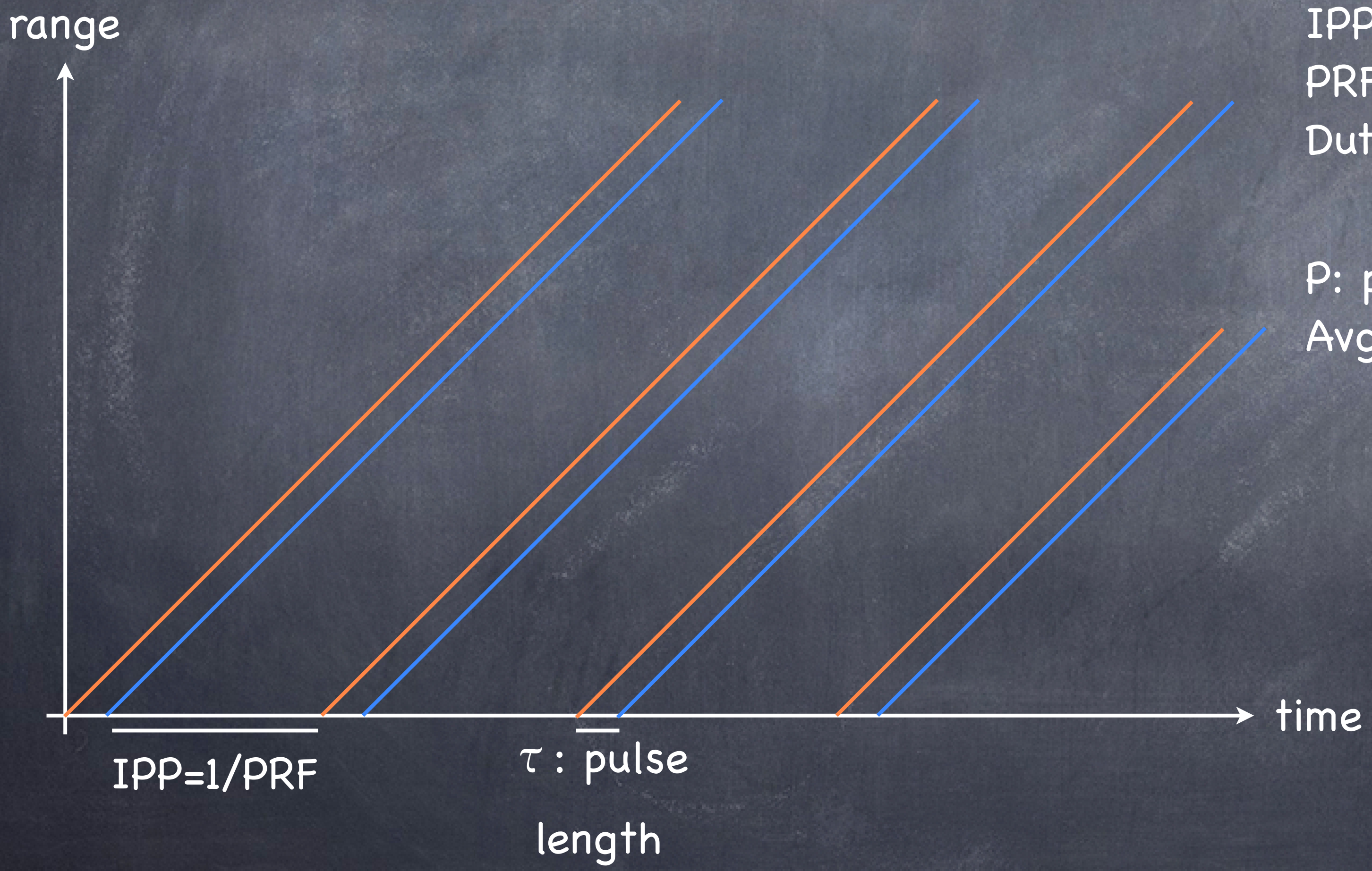
aka Point vs Volume Target

$$P_r = P_t \cdot \frac{4\pi A}{\lambda^2} \cdot \frac{1}{4\pi R^2} \cdot \frac{1}{L} \cdot \sigma \cdot \cancel{\frac{1}{4\pi R^2}} \cdot A$$

Received power is equal to
- transmitted power times
- transmitter gain times
- spread factor times
- any losses in the system times
- backscatter cross section times
- ~~spread factor at point target times~~
- receiver aperture.

Integration over beam-filling scatter volume results in cancellation of the target spread factor.

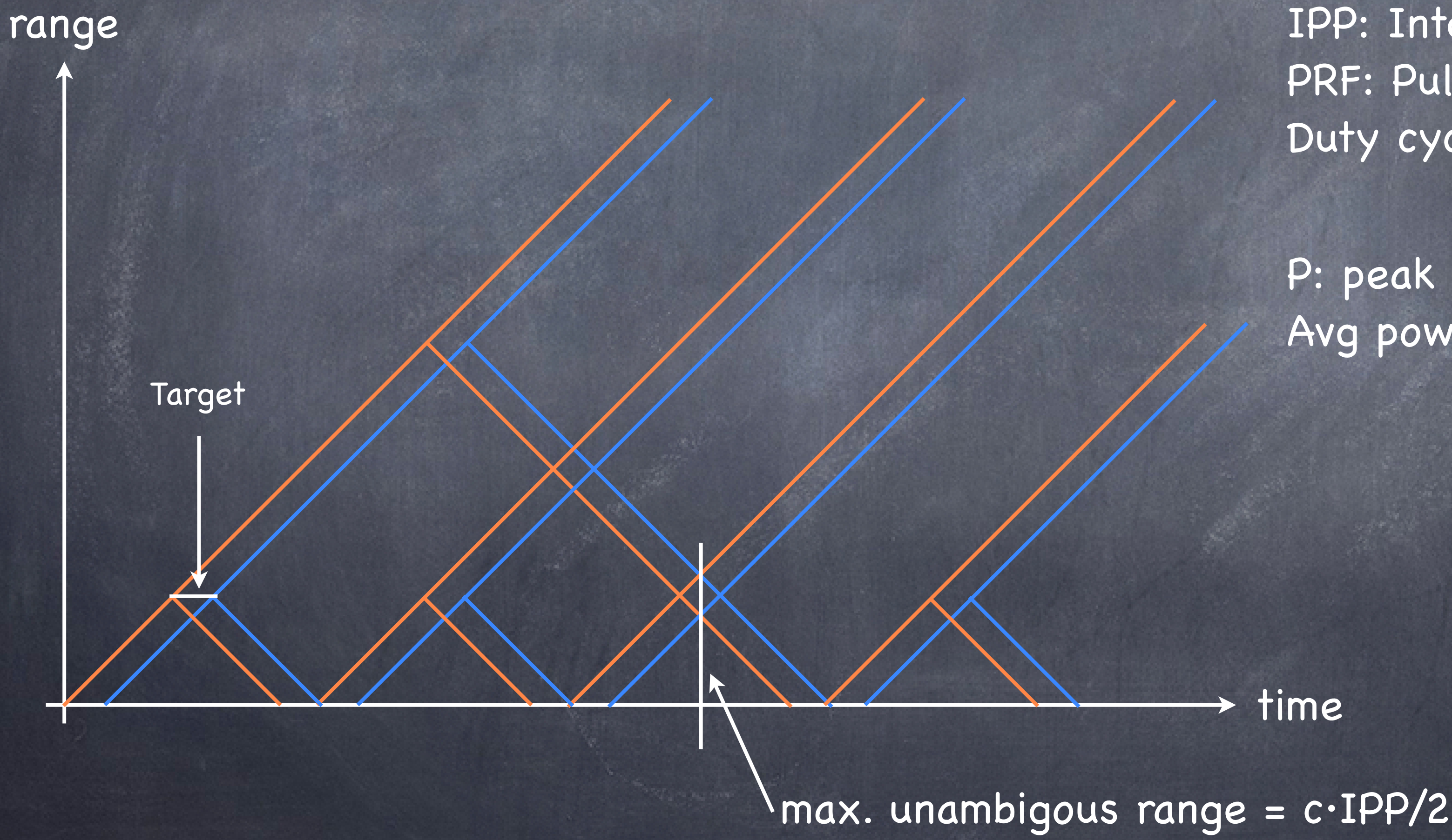
Pulsed Radar



IPP: Inter-pulse period
PRF: Pulse repetition freq
Duty cycle: τ /IPP

P: peak power
Avg power = P x duty cycle

Pulsed Radar



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Pulse coding

Pulsed Radar

IPP: Inter-pulse period
PRF: Pulse repetition freq
Duty cycle: τ /IPP

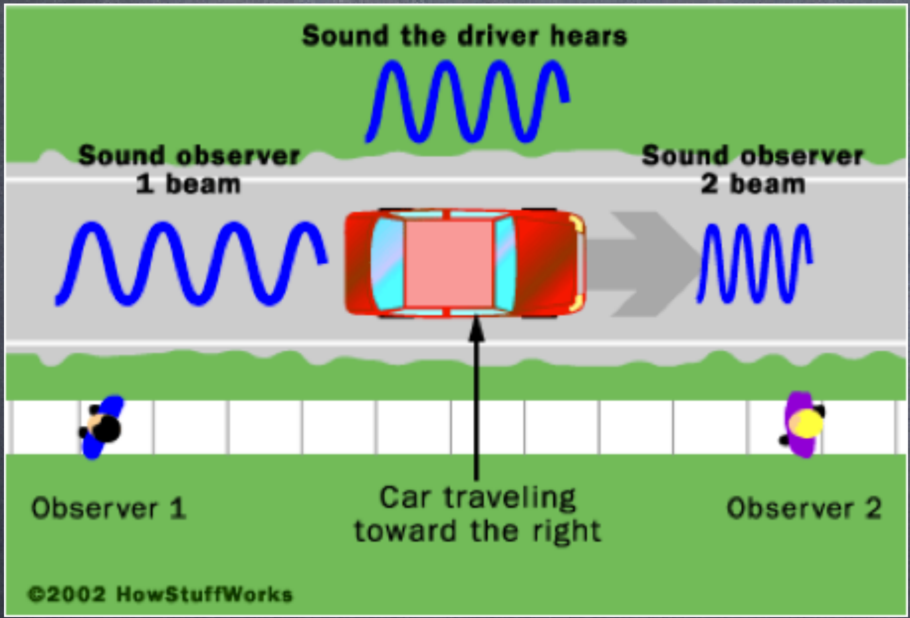
P: peak power
Avg power = P x duty cycle

Range resolution:
$\Delta r = c \cdot \tau / 2$

$1\mu s \Leftrightarrow 150m$

Pulse length	Range resolution
1 ns	15 cm
10 ns	1.5 m
100 ns	15 m
1 μs	150 m
10 μs	1.5 km
100 μs	15 km
1 ms	150 km

Doppler Radar



Return from moving target:

$\cos(2\pi f_o(t+2R/c)) =$
$\cos(2\pi(f_o+f_D)t)$
where
$R = vt$,
$f_D = 2f_o v/c = 2v/\lambda_o$

Resolving Doppler

- Tx signal: $\cos(2\pi f_0 t)$
- Doppler-shifted rx signal: $\cos(2\pi(f_0+f_D)t)$
- Multiply by tx signal, low-pass filter => Doppler frequency $\cos(2\pi f_D t)$
- Generate signal by mixing sin and cos using two oscillators 90° out of phase:
  $A\exp(i2\pi f_D t) = \cos(2\pi f_D t)+i\sin(2\pi f_D t) = I+iQ$
- Signed Doppler => signed radial velocity

Summary

- Pulse length => range resolution
- IPP => range ambiguity <=> time scale process
- Wavelength => scale of process/object
- Power, aperture, antenna design
  => scatter cross section, received signal
- Aperture, wavelength => far-field distance