RADAR

INTRODUCTION

RADAR
Acronym:
- **RA**dio
- **D**etection
- **A**nd
- **R**anging

Principle demonstrated 1904 by German engineer **Christian Hülsmeyer**!
Strong Development during WWII by Germany and Great Britain.

Different kinds of Radar Systems:
Ground based Radar
1. **Primary Radar Systems**
   Ground controlling Radar Systems
   - ASDE: Aerodrome Service Detection Equipment ("Taxi-Radar")

   Air Controll Radar Systems
   - PSR: Primary Surveillance Radar
   - SRE: Surveillance Radar Equipment
   - ASR: Aerodrome Surveillance Radar
   - PAR: Precision Approach Radar

Primary Radar: Slant Range + direction, no ALT!
Two reasons for introducing Primary Radar:
MIL reasons:
1. To detect any A/C not transmitting any transponder signals.
2. Politically not possible to force transponder in every A/C and everywhere in the same place where SSR is installed.

PSR: Primary Surveillance Radar: Active transmission, Passive response, e.mag. energy is partly reflected.

2. **Secondary Radar Systems**
   - DME: Distance Measuring equipment: Transponder
   - SSR-Interrogator: Secondary Radar

Airborne Radar
1. **Primary Radar Systems**
   Weather Radar (modern: Doppler principle)
   Doppler Radar Navigation System
   Radio (Radar) Altimeter
2. **Secondary Radar Systems**
   - DME: Distance Measuring equipment: Interrogator
   - SSR-Transponder: Secondary Radar

Secondary Radar: Slant Range + direction, ALT, ID!

ALT in 100 ft-steps, based on 1013 hPa
ID preselected by Pilot ("SQAWK")

SSR: Secondary Surveillance Radar: Active transmission, Active response by triggered transponder.

Technical Differences:

- **Continuous Transmission**
  Example:
  Radar-Altimeter: continuous transmission
- **Pulsed Transmission**: short bursts of el.mag. energy (ms)
  Mainly:
    Surveillance Primary Radar Systems
    Secondary Radar
    ➔ pulsed signals

Signal Propagation:
Propagation with speed of light: ca.300000 km/s

Measurement:
measuring Transit Time
➔ via speed of light c: Range/Distance.
➔ Surveillance Radars: searching space for targets: Surveilling Principle.

EXKURS
Radio astronomy -> passive signal detection. -> Passive Radar.

Frequency Bands:

UHF:

- DME: 962-1213 MHz,
- SSR-Interrogator: 1030 MHz,
- SSR-Transponder: 1090 MHz,
- SRE: ~1250-1350 MHz,
- ASR: ~2700-2900 MHz.

SHF:

- PAR: ~9 GHz,
- ASDE: > 20 GHz

EHF:

- ASDE: < 37.5 GHz

Wavelength
1 m (large), MHz MIL: 1 m, **L-Band**
1 cm (small), GHz CIV: 1 dm, **S-Band**, 1 cm, **X-Band**
Problem with antenna:

The larger the wavelength the larger the antenna due to angular resolution!

$$\theta = 70 \cdot \frac{\lambda}{d}$$

30 cm is largest wavelength in CIV Radar.
CIV: Taxi Radar: waves of 1 cm wavelength.

Too short wavelength -> absorption/damping in atmosphere.

The higher the frequency, the higher the absorption -> reduction of SERVICE RANGE!
MIL, Scientific: -> mm waves

Angular Resolution:
angular distance to distinguish two A/C!

Service Range:
Max. Distance to get usable Echo signals

High frequent CARRIER transports high energy!
3 cm wavelength -> 10 GHz = 10000 MHz

RADAR EQUIPMENT
Simplified Block Diagram of a Pulsed Radar

TIMER:
clock -> **"Pulse Repetition Frequency" (PRF)**

Pulse Modulation:
Low Freq.! (pulse/sec)

PRF is connected with range:

- low PRF for long range
- high PRF for short range

PRR: "Pulse Recurrence Rate" = "Pulse Repetition Rate"

PRI: "Pulse Repetition Interval"
Time separation of different pulses.

PRI = 1/PRF
Special case of period formula:

POWER SUPPLY:
Direct Current: DC

WAVEGUIDE
(Hohlleiter) to transmit wave to antenna

HOG HORN:
Opening of Waveguide to parabolic antenna.

ANTENNA:
Antenna is rotating.
Antenna is good for transmitting as for receiving as well!

Magnetron:
➔ Generates high frequencies with high power.

DUPLEXER:
Switch for Transmit/Receive-mode!
➔ from ca. 15-20 pulses, we need 5 ACCUMULATED PULSES TO INDICATE ECHO!

DISPLAY:
Indicator: **PPI "Plane Position Indicator"**

MIXER:
Mixing received wave with reference frequency, generated by a KLYSTRON (weaker Magnetron).

KLYSTRON: "Hollow space oscillator".
➔ Signal with lower frequency is generated, better to be handled by electronics.

DEMODULATOR
make signal DC -> direct "Video Signal"

AMPLIFIER:
Electronic to handle weak signal.
➔ Amplifier: for Video Signal.

CATHODE RAY TUBE (CRT):
➔ visible (not audible) "BLIP"

"BLIP", Echo, Backscatter

DEFLECTING COIL:
➔ Magnetic field -> Lorenz force deflects electron ray to the side.
➔ SAWTOOTH-CURRENT deflects ray -> Time Line
➔ Time measurement graphically -> Range Display
➔ Rotating antenna synchronized to rotating deflection coil -> Directional Information!
➔ 2D-image of situation.

This is the Radar Principle! Modern Systems transform into digital signals and display by software.

AZIMUTH: Angle in the horizontal plane, depending on Rotation of Antenna.
-> PPI, Plane Position Indicator.

DISTANCE AND PRF
The connection between distance and PRF.
Desired Range determines PRF

Maximum Distance to display:

$$d_{max_{theor}} = \frac{c \cdot PRI}{2} = \frac{c}{2 \cdot PRF}$$

Refinement of d_{max}:

$$d_{max} = \frac{c \cdot (PRI - Deadtime)}{2}$$

Reason:
-> WRONG SIGNAL: "**SIGNAL ON THE SECOND SWEEP**"!

SOLUTION:
-> DEAD TIME required to avoid signal on the second sweep! and to synchronize transmitting and receiving components.

ANTENNAS
Different kinds of antennas are in use:

- Parabolic Antennas: Usually Primary Radar.
- Beam Antennas: Usually Secondary Radars.
- Phased Array Antennas: Weather Radar.

  Lots of slots, connected with different receiver/transmitter channels
  - ➔ Phase shift
  - ➔ Interference
  - ➔ suppression/increasing
  - ➔ Steering the direction! (Lot of hardware/software inside)

Huygens Principle: Elementary waves from slots -> wave front -> directed wave.
PSR/SSR: JANUS-Configuration, double antennas

ANTENNA DIAGRAMS
Main Lobe
Side Lobes

Side Lobes has every directed antenna diagramm, due to diffraction ("Beugungseffekte")!
Side lobes are a problem for SRE!
Range measurement is OK!
Direction is wrong, because direction is defined as the direction of the main lobe!

Azimuthal Resolution, transversal resolution, horizontal resolution, half power resolution: theta.

The smaller theta, the better is the resolution:
- Taxi Radar: theta = 0.2°
- Enroute SRE: theta = 1°
- Airborne Radar: theta ~ 3°

HALF POWER DIAGRAM: outside half power -> signal energy is quickly dropping.

Range or Radial Resolution
1/2 Pulse Length (theoretically). In practice often the double! 1/2 Pulse Length for Radial Resolution is also theoretically the SHORTEST MEASURING DISTANCE!!

HIT NUMBER
15 - 20 Pulses are transmittet onto object per antenna sweep.
About 5 Reflections are neccessary to get pertaining illumination of the CRT-Coating!

With higher Resolution
➔ sharper picture
➔ this is the reason, because Taxi Radar has a very short wavelength and high PRR
➔ diagram: PENCIL BEAM

Ground Controlling Station use 2 different diagrams:
1. Pencil Beam -> long distance
2. Cosecant Square Diagram -> Short distance

Cosecant Square Diagram:

$$\operatorname{cosec}\alpha = \frac{1}{\sin\alpha}$$

$$\sec\alpha = \frac{1}{\cos\alpha}$$

$$r = h \cdot \frac{1}{\sin\alpha} = h \cdot \operatorname{cosec}\alpha$$

$$\rightarrow \quad P_{transmitted} = \underbrace{\left(\frac{S_{target} \cdot 4\pi h^2}{G}\right)}_{\downarrow} \cdot \operatorname{cosec}^2\alpha$$

$$\rightarrow \quad P_{transmitted} = const \cdot \operatorname{cosec}^2\alpha$$

$$\boxed{P_{transmitted} = const \cdot \operatorname{cosec}^2\alpha}$$

Cosecant Square Diagram: Power is transmitted in dependency of vertical angle.
Transmission of power is depending on vertical angle of radiation, according to achieve same signal strength of A/C in constant Altitude -> Transmission according formula!

POWER

Power density:

- from antenna energy is propagating into space with speed of light.
- power is energy rate
- power density S: power transiting perpendicular area.

Antenna beam: strengthening of the signal from isotropic into beam.
G: Gain, ("Verstärkungsfaktor")

WX-Radar in A/C operates with

- cosecant-square-diagram in MAP Mode!
- Pencil Beam - diagram in WX-Mode

RADAR FORMULA / EQUATION

Correlation between range and electrical parameters of the system.

$$r_{max} = \sqrt[4]{\frac{P_{transmitted} \cdot G \cdot \sigma \cdot A}{(4\pi)^2 r^4 \cdot P_{received_{min}}}}$$ Radar Equation

G: factor for gain
sigma: Reflecting Coefficient
dealing with electrical & geometrical, (size/shape/material) properties of an A/C.
A: Aperture, Factor = geometrical Cross Section of Antenna.
P-Receiver-Minimum: Minimum Power that the Receiver can pick up.

If we want to double the Range we have to increase Power by factor 16 !

➔ better increase RECEIVER SENSITIVITY!
➔ Radar Receivers have usually high sensitivity!

Radar Formula is good for free space transmission.

- Noise in the athmosphere
- Receiver Noise

RADAR WAVE PROPAGATION

UHF, SHF, EHF have Quasi-optical propagation.

MICROWAVE: lambda < 30 cm
-> Radar operates on microwaves.

"LINE OF SIGHT"-propagation
Quasi-optical propagation
Refraction, NOT diffraction (need obstacles)!
Radar - horizon is not exactly the geometrical horizon.
Refraction, because of different density of air. Like light ray. REFRACTION INDEX.
-> Radar Horizon is 15% farther than geometrical horizon (Rule of Thumb).

$$d_{max_{[NM]}} = 2 \cdot \left(\sqrt{H_{[m]}} + \sqrt{h_{[m]}} \right)$$

$$d_{max_{[NM]}} = 1.22 \cdot \left(\sqrt{H_{[ft]}} + \sqrt{h_{[ft]}} \right)$$

Geometrical: Calculate REFRACTION INDEX by replacing the EARTH RADIUS R by:

ATMOSPHERIC EFFECTS
Overrange
- Inversion: Hot over cold air

Reduced Range
- Layer of cold air over hot air

PROBLEMS OF PRIMARY RADAR SYSTEMS
Primary Radar has several Problems/Difficulties.

Moving Targets
Primary Radar: Indicates all targets, A/C and terrain! -> Difficult to detect A/C!
RADAR WITH MOVING TARGET INDICATION (MTI)
- ➔ SOLUTION: Comparision of phase of two reflected
- ➔ If Range to target doesnt change -> constant phase!
- ➔ If radial change of range (moving target) -> phase shift.

PRINCIPLE:
Constant range -> constant phase difference.

PROBLEMS WITH MOVING TARGETS
Phase difference is periodically: 0°-360°. If range between pulses is longer we can get same phase: **Blind Speed**

SOLUTION:
Using two PRFs creates 2 different Blind speeds.
While an A/C cannot have 2 blind speed at the same time, we have an indication at least on one PRF.
Sometimes 3 PRFs are used -> Staggered Pulse Repetition Frequency System

Further Problems of no indication:

- Circular suppression, cancelling.
- Tangential suppression, cancelling.

Rain
Rain drops have good reflecting property -> targets behind /in rain cannot be detected.
- In earlier times: gain was reduced -> stronger target signals remain.
- Today: Transmitting CIRCULA POLARIZED SIGNALS along propagation path.

Property of circular polarized signal depends on the geometry of the target:
Statistical aspect:
- 1 bounce back from sphere/plane,
- from A/C (irregular shape) -> usually 2 bounces back

Other Errors in Primary Radar
Multipath and Sidelobes.

MULTIPATH:
gives signal
➔ wrong direction
➔ "Ghost Target"

SIDELOBES:
➔ distance is correct, but direction is wrong, because direction is defined as the direction of the main lobe.

Sidelobes are not wanted but cannot technically be avoided!

COMPARISION OF ALL PRIMARY RADAR SYSTEMS
Common for all Surveillance Systems is the number of accumulated pulses ->

HIT NUMBER. number of accumulated pulses:
15-20 per second to get indication: Practically ca. 5 echo-pulses per second to generate a Blip.

EXAMPLE:
Airport Surveillance Radar (ASR, for instrument approaches):
- Angular resolution: alfa = 2°
- PRF = 900 Hz
- HN (Hit Number per antenna sweep) = 15

FIND: **Antenna Rotation Rate**, Revolution per Minute (RPM)?

$$\omega = \frac{360°}{T}, \quad \omega = \frac{\alpha}{t} \quad \rightarrow \quad t = \frac{\alpha}{\omega}$$

$$t = PRI \cdot HN \quad \rightarrow$$

$$\omega = \frac{\alpha}{PRI \cdot HN} = \frac{\alpha}{\frac{1}{PRF} \cdot HN} = \frac{2°}{\frac{1 \cdot 15}{900}} [\frac{°}{\sec}] =$$

$$= \frac{2°}{\frac{15}{900}} \cdot \frac{60}{360°} [RPM] = 20\,[RPM]$$

$$T = \frac{360°}{\omega} \quad \rightarrow$$

$$T = \frac{1[Revolution]}{20[RPM]} = \frac{1}{20\frac{1}{\min}} \cdot \frac{60\sec}{1\min} = 3\sec$$

Basic Parameter: Hit Number.
All technical parameters are based on HN!

Surveillance Radar: long range -> low rotation
Taxi Radar: short range -> high rotation
-> therefore Taxi radar needs 15000 PRF!

CONCLUSION
It is not possible to optimize a Radar for all tasks! Optimal for ONE task, for others: suboptimal!

PRECISION APPROACH RADAR PAR

Used for precision approach (MIL!), final approach segment. Primary Radar with vertical and horizontal guidance (3D), distance and direction.
Not common usage in civil approach.

Responsibility is by GROUND CONTROLLER! Pilot has to follow instruction! ("Talk down")

Precision approach:

- Initial segment
- Intermediate segment
- Final segment: GCA (no glide path)

In case of COM-failure:
5 sec no COM -> Go-Around or VISUAL langing.

Modern PAR-Antenna: motion generated electronically in the diagram.

AIRBORNE WEATHER (WX) RADAR
Airborne Primary Radar System.

WX-RADAR:
There is an optimum in reflection on rain drops.
- Larger lambda has less reflexion by geometry
- Smaller lambda has more absorption in rain -> less reflection

Frequency good for bad WX detection:
- lambda = 3 cm / 6 cm
- Working Freq.: 10 GHz

Two tasks for WX-Radar:
- Main Task: detect severe weather, thunderstorms, CBs, hail, precipitation, rain
- Secondary Task: Ground Mapping

Antenna diagram:
- Map Function: Cosecant-square-diagram
- WX Function: Pencil diagram

Map Function:
➔ for Terrestrial Navigation!
➔ For Position Checks!
To distinguish coast lines, river estuaries/ mouths, mountains.

Take the Radar Bearing (RB!).
For Chart Plotting: TB neccessary!

```
   CH
+DEV
=  MH
+VAR
=  TH
+  RB
=  TB
```

Range + Bearing = Position!

WX-Radar: PRF = 400 Hz
(Electronics in A/C operates usually on 400 Hz!)
Range: 100, 200, 300 NM; low Power
➔ depends on extension of precipitation for detection!
Pulse Length: 0,02 µs

Antenna: Parabolic or Phased Array
Diagram 2°-3° azimuthal
Usualy not Yaw-stabilized!
Today: yaw and tilt in sectors!

Tilt Angle 12-15° Up/Down
Tilt, to detect weather in, below or above climb path!

Using Tilt angle to check upper boundary of CB!
➔ checking height of CB
➔ ALT of upper layer

No high resolution is needed for WX-Radar
➔ Pulse length: 1-3 µs
➔ no need of high power!

For mapping wee need higher resolution -> CONFLICT!
Solution: **"Pulse Compression"**
Done by modulation: Frequency modulation.

- Frequency is changing linearly, increasing over pulse length.
- Receiver can distinguish by comparision nearby objects:

Deceleration of frequency -> gives information of close objects by reflected signals without gap!

WX-Display monochromatic
Digital Picture:

- Range Rings
- Bearing Marks
- Functional Button:
- TST
- Range Selector
- Tilt Knob
- "NOR"=normal: WX function
- "MAP": Map function

WX is very bad for NAV:
- you have to GUESS bearing
- you have to GUESS distance

In modern coloured systems/displays -> no contour cycles neccessary -> precipitation areas (former black holes) are red.

FRINGES: determine turbulence

dark	no ...
green	slight ..
yellow	moderate ...
red	strong ...
purple	severe precipitation/turbulence

Important: RELATIVE MOTION display!

INTENSITY: strengthening the electron beam in the CRT: -> brightening (Signal is not affected, only brighter!)
GAIN: affects signal itself. Gain is connected to SENSITIVITY of the RECEIVER.

Test function: TST
- Older systems transmitt! Take care for maintenance people!
- Modern systems: only antenna is moved around.

Modern development:
WX-antenna usually sweeps to left + right.
Select azimuth and make vertical sweep +/-15° -> 3D-information about WX situation.

Summary WX-RADAR:
lambda = 3 cm / 6 cm
Working Freq.: 10 GHz
WX-Radar: PRF = 400 Hz
Pulse Length: 2,5 µs
theta = 3-9°
Reichweite 150-300 NM
Tilt Angle 12-15° Up/Down
Antenna diagram:
    Map Function: Cosecant-square-diagram
    WX Function: Pencil diagram
Tilt Lever/Button

SECONDARY RADAR SYSTEM
Introduced in the 1970's.
Called secondary by historical reasons.

Secondary Radar System gives more info:
- Slant Range
- Direction
- ID
- ALT

Airborne TRANSPONDER involved:
- Receiver: transmitting &
- Transmitter: responding

USA: ATC transponder is called "**ATC Radar Beacon System**".

Advantage:
less signal power required.
- Primary radar: for 150 NM range -> up to 5 MW Power!
- Secondary radar: for 200 NM -> 1.5 - 2 kW!

Signal only needs to travel in 1 direction. Triggered transponder gives signal back.

All over the world:
Secondary radar frequencies:
- 1030 MHz for transmitting
- 1090 MHz for receiving (Ground Receiving Frequency)

Transponder receives 1030 MHz, transmitts (responds) on 1090 MHz -> Offset of 60 MHz.

PROBLEM
Different Secondary Radar Systems are working on the same frequency.
How to distinguish from other secondary stations?

Solution:
Different, individual pulse repetition frequency for every secondary radar station!

Transponder Modes
MODE Time separation of double pulses
1 MIL .... 3 µs
2 MIL .... 5 µs
3/**A CIV**/MIL .... 8 µs -> ID
B CIV .... 17 µs, in the 80's, triggering ID, not longer existing
C CIV .... 21 µs -> ID + ALT (barometric)
(D CIV .... 25 µs never introduced)
S: "Selective" -> Component of the TCAS-System.
capable of simulating A+C-mode,
recognizes A+C-pulses.

Technically a mode is defined by double pulses. Time separation defines the mode.

ID ("**Squawk**") is coordinated with ATC (or automatically adjusted according to flight rules applied):
VFR
0012 USA
2100 Germany
Pilot selects 4 digit number: SQUAWK -> max number is: 7777 !

Mode interlace:
- ACAC
- AACAAC
- AACCAACC
- ...

"Train of Information"
Information (ID) is included in two Frame Pulses F1, F2. 20.3 µs.
12 pulses carry information. 2^{12} is the number of combinations -> 4906 codings are possible.

Special Position Identification Pulse SPI

➔ for "Squawk IDENT"
➔ additional pulse is transmitted

For **Altitude encoding** we need at max 11 pulses.
Altimeter encodes automatically, in 100 ft steps related to standard pressure 1013 hPa.

Old transponder: 2 digits -> interlaced pulsed for 4 digits. Nothing to do with mathematical binary or octal coding:

77	EMERGENCY	7700
76	ENGINE FAILURE	7600
75	HIGHJACKED	7500

PROBLEMS WITH SECONDARY RADAR SYSTEMS

- "Fruits" -> "Defruiter" device
- Side lobe echos -> "Side Lobe Suppression Pulse"
- Multipath -> Dynamic Thresholding
- Traffic overload -> "Whisper-Shout"

No problems with:

- rain
- moving targets
- power

ACAS

INTRODUCTION TO TCAS

TCAS means:

- **T**raffic Alert &
- **C**ollision
- **A**voidance
- **S**ystem

TCAS is one of the few operational **ACAS**:
Airborne
Collision
Avoidance
Systems

Based on airborne XPDRs (Part of the Secondary Radar System).
Development since 30 years.
System tries to prevent midair Collisions by timely warning given to the pilot.

Gives additional TRAFFIC ALERTS (TA, alerts - and nothing else)!
In later versions also RESOLUTION ADVISORIES (RA, advisories - and nothing else), how to evade the critical situation!

Mandatory in USA for all passenger A/C.

3 types of TCAS:

- TCAS I
- TCAS II operational
- TCAS III

- TCAS I = TCAD: USA: gives TA only; mandatory for A/C 10 < 30 seats. Will NOT give RA (climb, descent, turn)
- TCAS II: Operational; provides TA and vertical RA (climb descent); USA: mandatory for all A/C with > 30 seats
- TCAS III: Still test phase. Same as TCAS I/II, provides RA with maneuvres in the horizontal plane (according Allied Signal: doutable!).

USA: mandatory for passenger A/C, not for cargo freighters or military A/C. Otherwise midair bevore Angola with Luftwaffe A/C would have been avoided!

TCAS is no 100% System!! But better than nothing! -> No 100% Safety to avoid collisions.

BASIC CONCEPT

TCAS is a ground independent system. Based on available airborne XPDRs (Mode A/C, S).

Surveillance Range: Area of 20 - 40 NM around own A/C. Other A/C are tracked to +/-100 FL.
In this airspace volume own TCAS system sends signals
- ➔ triggers XPDRs of other A/C
- ➔ responding to TCAS.

NEAR MISS SITUATION
Near Miss Situation and related motions:
- True Motion
- Relative Motion
- Radial Motion

Collision Plane
CPA: Closest Point of Approach
TCPA: Time to Closest Point of Approach

Traffic Display:
- Off Centered Display
- Headup orientation
- North orientation

Radar-Plotting:
- Intruder
- Tracking of Intruder

For Radar-Plotting a good angular resolution is required!

INTRUDER:
A/C in vicinity, closing up!

Because of rough bearing measurement NO direction information is used to derive RA
-> only maneuvres in the vertical direction can be advised (climb, descent)!

Also NO precise tracking of intruder is possible!

CPA can only be calculated with accurate bearings!
-> TCAS cannot calculate CPA!!!

How can TCAS than detect a critical situation?
- Idea: Questioning the XPDRs in the vicinity -> slant range.
- With the time of the interrogation repetition interval (usually 1 sec!) TCAS can calculate the RANGE RATE (Radial Velocity)!
- Mode C/S -> ALT information of other A/C.
- With own ALT -> ALT difference,
- with time -> Change in ALT -> check of intruder situation -> derive RA.

Minimum Vertical Separation (Miss Distance) at CPA!
-> Linear prediction of DeltaH (by lots of algorithms)
-> System is a little bit abstract.

Measurements:
- Slant Range: r
- Range rate: `r = r/t
- Altitude
- Altitude Difference: DeltaH
- Change of Altitude: Delta`H = DeltaH/t

COMPONENTS OF TCAS
- TCAS consists of:
- LISTE
- TCAS Computer
- Transmitting/receiving Module
- Antennas at top/bottom of A/C
- Mode S XPDR: 2 functions here:
  - Surveillance with GND SSR (simulates Mode A/C).
  - Communication with other TCAS-A/C.
- Control Panel
- TA Display: visual info for Pilot about TA
- TCAS Display: visual info for Pilot about situation
- RA Display: = modified Vertical Speed Indicator
- Integrated in FMS, if available (Primary Flight Display + NAV Display)
- Voice Annunciation, aural alert ("TRAFFIC, TRAFFIC", etc.)

Directional top antenna is not rotating! Segmented in 4 or 8 segments

Freqs. same as in Secondary Radar Systems:
- 1030 MHz Interrogator
- 1090 MHz XPDR

TCAS LOGIC
PROTECTED VOLUME OF AIRSPACE is generated (between the two A/Cs).
Protected volume adapts to relative speed (Range Rate).
-> Criterium: CONSTANT WARNING TIME! Tau-Criterion, will not depend on direction of A/Cs.

Don't mix Protected Volume of Airspace with SURVEILLANCE VOLUME!

INTERFERENCE LIMITING CONTROL.
7 SENSITIVITY LEVELS of TCAS.
In high traffic TCAS will suppress SSR-signals.
➔ Updating on ATC-SSR-radar is delayed (up to 12 sec)
➔ ICAO demands: suppression should not be more than 2% of the time!
TCAS reduces sensitivity level automatically with altitude. Mode S allows data link!

Reduction of Warning Time:
- If too many TCAS A/C around there is a reduction of transmission rate and power of own TCAS -> warning time will significantly be reduced!!
- If speed (rel.) is overhelming 500 kt (ICAO!) -> if RA comes, react immediately!! But don't over-react!
- Higher acceleration is also not covered by the system. -> warning time will be only 12 to 15 sec!

Pilot Display:
- Visual Display
- Aural annunciation
  - TRAFFIC TRAFFIC
  - CLIMB CLIMB
  - DESCENT DESCENT
  - ...

Threat Detection:
- Range Test,
- Altitude Test -> at least Mode C XPDR must be in other A/C!

Only if both tests passed (positive) intruder is declared a threat!

Threat Resolution selection:
Resolution Strength: RA strength depending on FL:
vertical separation 400-700 ft

Coordination: with other TCAS-A/C via Mode S XPDR, also coordination with ground station SSR that there is a TCAS maneuvre -> pilot has to coordinate with ATC!!

GEOMETRY OF PROTECTED AIRSPACE VOLUME
RANGE TEST
Range test -> Spheric volume.

TAU-CRITERION
"Range over Range-Rate"

Modified Tau-criterion
Extension too big: lots of unneccessary alarms!

New Tau-Criterion:
- Reduces alarms by 50%!
- (Little bit less) acceleration protection!
- Minimum separation is guaranteed!
- Reduces alarms by 50%!

End of alarm ("CLEAR OF CONFLICT")

ALTITUDE TEST
Additional vertical motion is also covered: Cut of protected volume in altitude because FL-change should not create an alarm!
-> "VERTICAL TAU-TEST".

INTERFERENCE LIMITING CONTROL
SURVEILLANCE OF TCAS
There are different techniques to interrogate Mod C XPDRs and Mode S XPDRs.

Whisper Shout Technique
Problems of Secondary Radar in dense A/C population -> code garbling, overlapping.

Solution:
➔ "Whisper Shout" transmission:
➔ Linear increase of signal strength:
➔ first lower power -> only transponder with high sensitivity will answer -> suppression pulse makes them silent -> only low sensitivity transponders will answer.
➔ sequencing of transponders
➔ in 1 sec diagram is swapping around -> sectional sequencing.
Update period: 1 sec.

Dynamic Thresholding
Sensitivity of receiver is slowed down after first pulse returns!

Multipath: suppressed by dynamic thresholding.

Surveillance of Mode S XPDRs:
- is different from surveillance of Mode C XPDRs!
- Mode S interrogation comes to Mode C transponder -> 2 pulses for side lobe suppression -> answers are suppressed for 45 µs
- Data package contains DIGITAL INFORMATION: phase switching (**Phase Modulation**)
- Mode S XPDR is answering: different in coding: No phase shift, pulse shifting: PULSE POSITION MODULATION.
- Answer in this modulation to simulate Mode A/C-XPDR!

No need to question Mode S XPDR all the time because of ID of Mode S XPDR! -> ID is stored.
"SQUITTER SIGNAL" every second the ID is transmitted by the XPDR -> no danger of Code Garbling!

Staggering answers to TCAS Mode S XPDR by whisper shout method.
All Mode A/C XPDRs that answered detect the "side lobe" suppression pulse -> XPDR with low sensitivity /farther away will answer.

Mode S signal is different from Mode A/C
Mode C XPDR will not answer to Mode S interrogation because of side lobe suppression pulse P1/P2.

Reduce frequency of active asking to reduce signals -> not more than 2% of time channel is blocked -> other times passively listening.

SENSITIVITY LEVEL

TCAS adapts sensitivity level automatically to actual altitude.

Sensitivity Level: Threshold Tau parameter for Range Test changes with altitude:

- Level 1 for taxiing (not yet defined)
- Below 500! no RA (NA means: Not Authorized) -> too dangerous!
- Level 2 for pilots use! Select only lower level!
- The higher the ALT, the bigger is the sensitivity level because lack in information, rougher measurement. But also FL-separation is bigger in high ALT (1000'-2000' separation).

➔ sensitivity level is increased with altitude!

TA comes 15 sec before RA!

Problems with GND CTRL and autonomous TCAS have to be solved -> pilots, airlines and controller are talking together.

TCAS III should allow HORIZONTAL RA!

THREAT RESOLUTION ALGORITHM

Threat Resolution Algorithm applies if threat is detected and Traffic Alert was given.

Threat Resolution Algorithm:

- Sense Selection
- Strength Selection

Two modelled maneuvres:

- Climb
- Descent

CLIMB under "down"-sense and DESCENT under "up"-sense:

TCAS-A/C, Mode C-Intruder:
Mode C-A/C may detect threat not at all!

What with 2 TCAS-A/C?
➔ Coordinate maneuvres in vertical plane

MULTIPLE INTRUDER LOGIC

If more than 2 A/C -> multi-A/C situation.
➔ TCAS has "Multi-A/C-Logic"

Up to 40 A/C will be surveilled.

In 3 A/C-situation: Today reversion of maneuvres is possible!
➔ Be aware of changing RA's as from TCAS II V6.7 to TCAS II V7.0 !

TCAS Pilot Display
INDICATIONS:
TA-display: in FMS integrated:
- NAV-Display is used for TCAS!
- EFIS: Maneuvre is indicated in Primary Display!

Threat Display:
- Intruder: white diamond, displayed in A340 only if TA or RA is given!
- TA Intruder: yellow circle, Voice: TRAFFIC TRAFFIC; Slant Range, vertical separation
- RA Intruder: Red square, Voice: CLIMB CLIMB CLIMB -> check vertical speed indicate and keep needle out of red band (and bring it into the green band).

Direction information is only between 5°-10° accurate! It can therefore NOT be used for algorithms!
Only used for additional information (Bearing to intruder is not neccessary for TCAS II!).