Кафедра електроніки, робототехніки і технологій моніторингу та інтернету речей
Факультет аеронавігації, електроніки та телекомунікацій (ФАЕТ)

ЕРМІТ

Електронні системи

Electronic Systems

Lecture #17

Яновський, Фелікс Йосипович
професор, доктор технічних наук,
лауреат Державної премії України, IEEE Fellow

Орієнтовний тематичний план лекцій

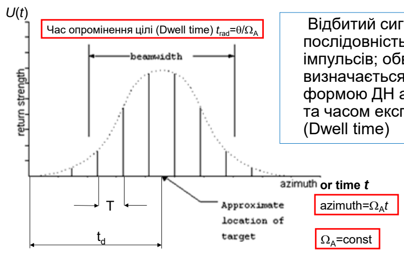
Основи теорії систем, сигнали і первинні перетворювачі електронних систем

Електронні системи локації

Вимірювання кутових координат

Contents

Вимірювання кута під час сканування антени



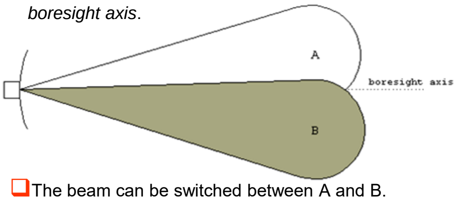
Відбитий сигнал - це послідовність імпульсів; обвідна їх визначається формою ДН антени та часом експозиції (Dwell time)

Макс. відповідає моменту часу , коли вісь антени спрямована на ціль [$dU(t)/dt=0$].

6

Dual-beam system

- The accuracy can be improved by using a dual-beam system. The two beams are offset in angle by a small amount to either side.
- The center between the beams is known as the *boresight axis*.



- The beam can be switched between A and B.

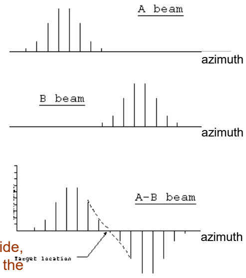
7

Constructing the dual beam output

Now when a dual-beam system scans across a target, the return will be the sum of the two beams.

If one of the beams is inverted (or made out-of-phase), the result will have a well-defined location of the target, namely where the difference between the beams is zero.

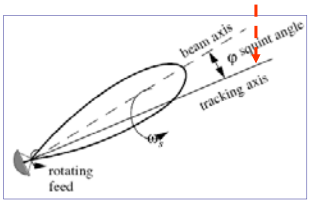
For a typical radar beam of 3^0 wide, a dual-beam system could track the target with 0.1^0 accuracy



8

Conical scan – Tracking

- Conical scan is a logical development of the consequent switch of the beam.
- In this case the antenna is continuously rotating at the displaced beam form the center.



Based on this, one can build a tracking system, which provides the directing the central axis (boresight axis) to the target. That is, the target will be on the tracking axis.

9

The difference is important!

- Nice feature of the dual-beam system is that the return strength varies nearly linearly in the vicinity of the target. Therefore it is easy to measure the target location even if the boresight is not directly on the target.
- The difference in target location and the boresight will be linearly proportional to the return strength as long as the target is not too far off center.

This is the key idea of monopulse measurement!

But in MONOPULSE all beams are generated simultaneously rather than sequentially.

10

Why do we need the monopulse method?

- Angle tracking based on conical scan or beam switch are limited essentially.
- RCS can be strongly changed in time.
- If the tracking is done using pulses transmitted in different time, the reflections can be ambiguously changed by amplitude, not allowing to capture the target.
- The solution now is obvious: it is necessary to transmit both pulses simultaneously.

11

The principle of monopulse direction finding

As in angular measurement in general, monopulse direction finding has two main methods:

- **Amplitude**

  and

- **Phase**

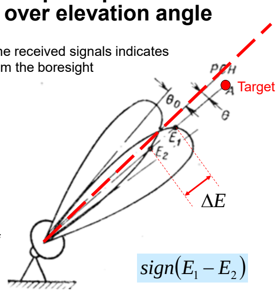
12

The monopulse principle at the amplitude DF over elevation angle

$\Delta E = 0$

Difference of amplitudes of the received signals indicates the value of displacement from the boresight

$\Delta E = |E_1 - E_2|$



The sign of this difference characterizes the direction of this displacement from the boresight

$sign(E_1 - E_2)$

13

The azimuth of the target is determined similarly using the azimuth channel receiver and the second pair of antenna patterns in the azimuthal plane.

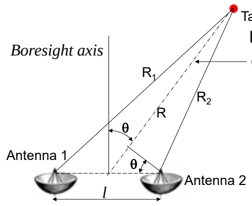
14

The monopulse principle at the phase DF

- In systems with phase monopulse DF, the direction to the target in a coordinate plane is determined by comparing the phases of the signals received by the two antennas simultaneously.
- In the far zone, each antenna illuminates the same volume of space, resulting in outgoing from a point target signals are virtually identical in amplitude but different in phase.

15

Monopulse principle at the phase DF



Line of sight forms angle θ with boresight axis

$$R_1 = R + \frac{l}{2}\sin\theta$$

$$R_2 = R - \frac{l}{2}\sin\theta$$

$$\Delta R = R_1 - R_2 = l\sin\theta$$

$$\Delta\varphi = \frac{2\pi}{\lambda}\Delta R = \frac{2\pi l}{\lambda}\sin\theta \qquad \Delta\varphi = \Delta\varphi(\theta)$$

This allows to determine θ from Δφ.

16

Ambiguity of monopulse phase measurements

Δφ =0 not only at θ=0, but also at other displacement angles, which correspond to the condition:

$$\theta = \arcsin\frac{\lambda}{l}n, \quad \text{where} \quad n = 1, 2, \cdots,$$

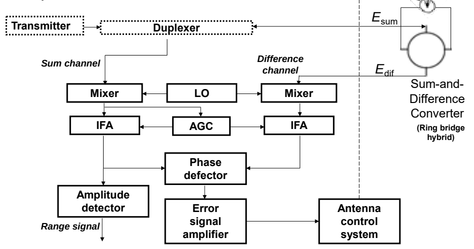
- Because of this, the DF characteristic is alternating turns, having along with the main direction, many wrong directions to "target".
- However, the ambiguity is not a serious disadvantage if the false directions are located outside the main lobe of the antenna pattern : Θ≤θ при n=1.
- Practically, this requires that the distance between the centers of the antennas does not exceed the diameter of each of them, for example, two adjacent antenna are OK.

17

18

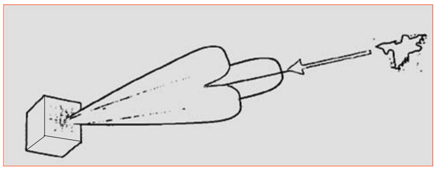
Amplitude SaD monopulse system

SaD system is less demanding on the identity and other characteristics of receiving channels, so it is widely used in modern radar.



19

Monopulse antenna pattern with sum and difference beam



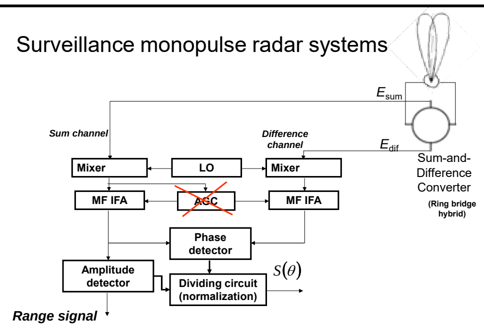
20

Surveillance monopulse radar systems

- Surveillance monopulse systems determines the coordinates of all targets, located within the antenna, that are resolved in range for each position of the beam in the space.
- When many targets are subjected to the processing, the AGC can not be used because AGC has inertia and does not have enough time to work on several closely spaced targets.
- Therefore, the normalization is not performed using the AGC in IF-section, but in the video section after the phase detector by dividing the output signal by the sum signal.
- It can be shown that such normalization provides the same result as the AGC that done at IF.

21

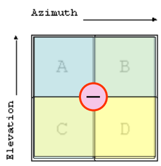
Surveillance monopulse radar systems



22

4 antennas and SaD discriminator

- In fact such monopulse system uses two dual-beam antennas; one along the azimuth plane and another one along the elevation.
- Pairwise measurements are made using 4 beams.



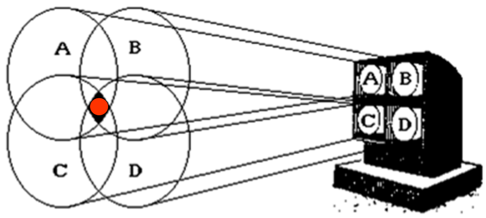
Azimuth error: (A+C) – (B+D)

Elevation error: (A+B) – (C+D)

- Dual-beam systems are generally used when high accuracy is required.
- Homing guidance
- Secondary radar mode S (ICAO).

23

Monopulse radar principle



AZIMUTH ERROR = (A + C) - (B + D)
IF (A + C) - (B + D) = 0, THEN NO ERROR

IF A = B = C = D
THE TARGET IS CENTERED

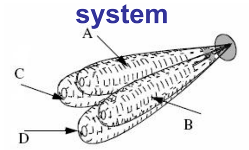
ELEVATION ERROR = (A + B) - (C + D)
IF (A + B) - (C + D) = 0, THEN NO ERROR

24

Four Beams – Single Pulse

- To form MONOPULSE antenna pattern, a special antenna feed is used to provide 4 beams using a single pulse.
- Hence it appears the name "monopulse."

Antenna pattern of a monopulse system

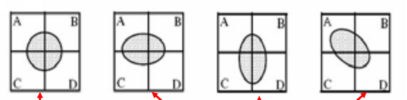


4 beams A, B, C and D represent 4 positions of a beam at conical scan.
4 feeds, e.g. horns, are used to form the antenna pattern.

Remind that at amplitude monopulse processing it is necessary to keep the same phase in all 4 beams.

Illustration of monopulse concept

A good way to explain the concept of amplitude monopulse technique is to represent the target echo signal by a circle centered at the antenna's tracking axis. The four quadrants represent the four beams.



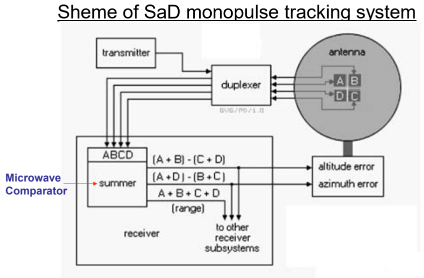
In this case, the four horns receive an equal amount of energy, which indicates that the target is located on the antenna's tracking axis.

When the target is off the tracking axis, an unbalance of energy occurs in the different beams.

Monopulse Procedure

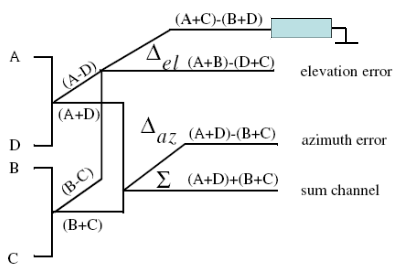
- Monopulse processing consists of calculating **sum** Σ and two **difference** Δ signals, obtained with different beams (azimuth Δ_{az} and elevation Δ_{el}).
- Then dividing the voltage of the difference channel Δ by the voltage of the sum channel Σ, we determine the angle of arrival.
- A radar system continuously compares amplitudes and phases of the signals from all beams to determine the value of target displacement from the boresight.
- It is important to keep the phases of all 4 signals were constant in the modes of transmission and reception.
- To form sum and difference signals normally **digital networks** or **microwave comparator**s are used.

Sheme of SaD monopulse tracking system



Turning the antenna the system reaches the maximum sum and the minimum difference.

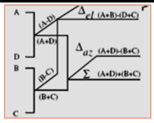
Typical Microwave Comparator



Implementations of microwave comparators

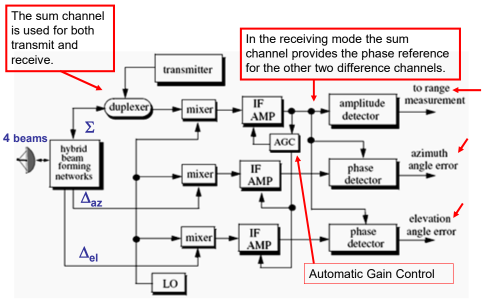
- **hybrid [magic] T**
- **slot bridge hybrid**
- **microwave circulator**
- and other **microwave bridges**

Amplitude Comparison Monopulse Procedure

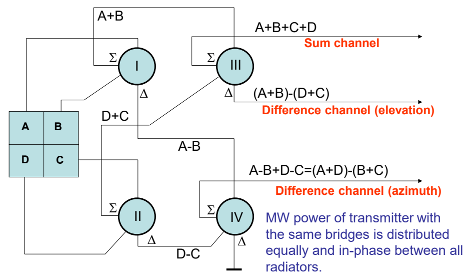


- To get the difference on elevation it is enough to use just one of differences: (**A-D**), (**B-C**), (**A-C**) or (**B-D**). But if the sum pattern (**A+B**) and (**D+C**) is get first and then the difference **(A+B)-(D+C)** is calculated, we obtain more powerful difference signal Δ_{el} .
- Similarly, forming sum patterns (A+D) and (B+C), and then calculating the difference **(A+D)-(B+C)**, we obtain more powerful azimuth signal Δ_{az} .

A radar with DF in two planes



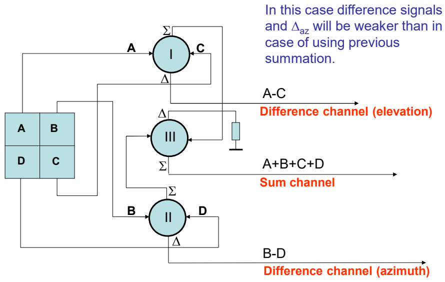
Scheme of the sum and difference signals in the application of the four guide bridges



MW power of transmitter with the same bridges is distributed equally and in-phase between all radiators.

Scheme for forming sum and difference signals using three waveguide bridges

In this case difference signals Δ_{el} and Δ_{az} will be weaker than in case of using previous summation.



Comparison of amplitude and phase SaD monopulse systems

- A and Ph SaD monopulse systms are completely identical in view of processing method, but they have principal differences in antenna pattern forming.
- Target angular information in A system is contained in the ratio of amplitudes, and in phase system it is contained in phase displacement that is caused path difference that corresponds to appropriate channels.

Combined monopulse systems

- The basis of combined systems is forming antenna patterns that provides getting independent information about the target **simultaneously using amplitude phase relations** of received signals.
- In this case, it is possible to manage DF in two planes using **only two mutually related channels** with a single wave guide bridge at their input.
- Signals in two channels differ by amplitude and by phase..

37

Combined monopulse systems (2)

- Two beams formed by the antenna in vertical plane are inclined to each other by angle $\boldsymbol{2\theta_0}$, and in horizontal plane they are parallel and spaced by distance $\boldsymbol{l}$.
- This provides the target DF in vertical plane by the amplitude method, and in horizontal plane – by the phase method.