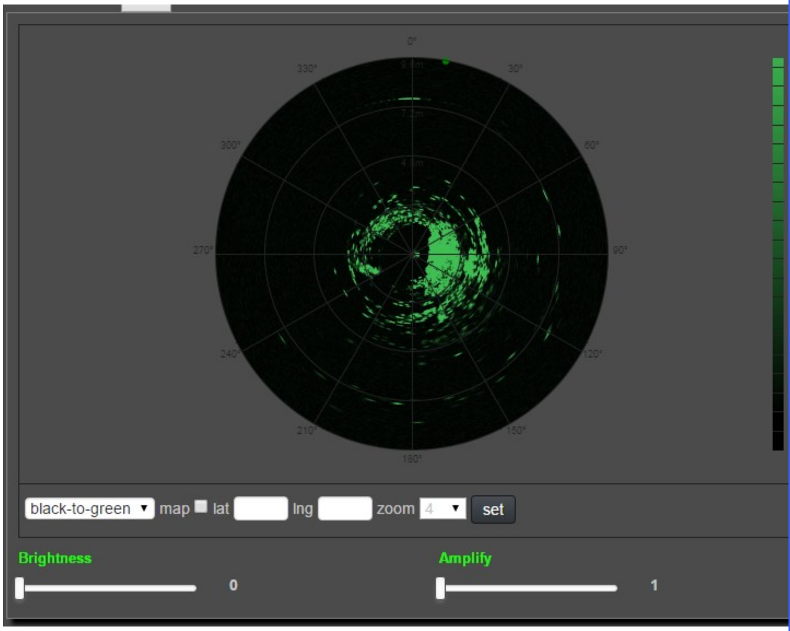
SkyRadar Modular Radar Training System
PSR Simulators Pulse, CW and FMCW



For details please contact:
The SkyRadar Consortium
www.SkyRadar.com
info@skyradar.com

Imprint

The SkyRadar Consortium
www.SkyRadar.com
info@skyradar.com

Visitor Address in France

SkyRadar
E. Space Park, Bâtiment D
45 Allée des Ormes
06250 MouginsFrance

Visitor Address in Germany:

SkyRadar
Am Schmachtenberg 11
58636 Iserlohn
Germany

SkyRadar Modular Radar Simulators PSR Pulse, CW (Doppler) and FMCW

1 RADAR FUNDAMENTALS

The process of detecting objects in space and the determination of their coordinates by electronic methods is called radiolocation. Devices providing the location of objects in space by the means of radio-waves are called radars (radar). By the principle of design and operation there are several types of radar:

- *Active and passive*.
  - Passive radars contain only passive radar antenna and receiver.
  - In the structure of the active radar persist also transmitter.
- Pulsed and continuous wave:
  - continuous wave (CW),
  - Doppler,
  - Continuous wave with linear frequency modulation (FMCW).

The main radar functions lie in determining:

1. Range or distance (from pulse delay)
2. Velocity (from Doppler frequency shift)
3. Angular direction (from antenna pointing)

For navigation at sea and in the air the following primary radar design primarily finds application:

- The two-coordinate active pulse radar also called Primary Surveillance Radar (PSR).

In the classical design, a cathode ray tube (CRT) with brightness mark or liquid crystal display (on some modern stations) is used as display. The echo signal is amplified by the radar receiver and converted into a video pulse passed to the indicator.

Navigation radars measure two parameters in polar coordinates:

- distance and
- direction of an object (azimuth angle).

The target range is the fundamental quantity measured by most radars. It is obtained by recording the round trip travel time of a pulse. Distance measurement is performed through the amplitude (pulse) method. The distance to the object is determined by measuring the time t_D from the moment of radiation ("probing") to the moment of reception of the reflected pulse. Time t_D is defined as the time of the pulse moving to the object and returning to radar:

$$t_D = \frac{2 \cdot D}{c}$$

where D – distance do object that often named as range;

c – light (radio wave) speed.

By the time t_D we can obtain distance to the object:

$$D = {}^{1}\!/_{2}\, t_D \cdot c$$

Range scale M_D is determined as relation of maximal range R_{max} to the radius R_{PPI} of PPI display. With this scale we can obtain the distance to the object as:

$$D = r_{onPPI} \cdot M_D = r_{onPPI} \cdot R_{max}/R_{PPI}$$

The scale is proportional to the scan rate: the higher the scan rate the larger the scale of the radar picture. Since the geometric length of the scan does not change, the increase of scale (zooming) radius will lead to a decrease of the surveillance area. The scale of the image called range scale, indicates the range of view (at the beginning of the sweep in the center of the screen). The distance to the object can be captured through an electronic ruler for range (distance) with brightness marks.

Determination of the angular coordinates of objects is based on the use of highly directional antennas. The surveillance radar uses the maximum amplitude method. In the method of maximum direction, the antenna is rotated continuously, and measurement of target angle is made at a time when the amplitude of the signal at the input of the receiver is maximized. Modern stations contain automatic object tracking in range and angle.

The pulse radar method allows a quite simple approach but at the same time it perceives several objects located in area of the radar, because echoes are shifted in time depending on the distance to the object. The solution to this problem with the continuous radiation will lead to a large hardware complexity. It is also possible to measure long distances at small sizes and devices used to transmit and receive signals share the same antenna. These reasons, in spite of the shortcomings inherent in the method are decisive in the selection of the pulse method for building surveillance radars.

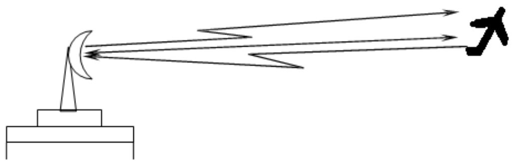


Fig. 1 The principle of operation of radar

2 THE BASIC CHARACTERISTICS OF A RADAR

For Air Traffic Controllers visual representation of the surrounding terrain as given by Primary Surveillance Radars is of particular importance. The image quality and the usefulness of radar pictures for navigation, is directly dependent on the technical and tactical characteristics of the parameters of the radar. In the following, this chapter gives the basic information and knowledge essential for understanding the process of formation of the radar picture.

2.1 The directionality of the radiation

The PSR's antennas use a wide variety of structures that form the narrow radar beam in the horizontal and sometimes in vertical planes. But they are, in addition to the main beam (main lobe) portional to their surrounding electromagnetic energy scatter, forming a so-called side-lobes. Those side-lobes can be the sources of false alarms.

Since the rotation angle of the antenna during the time between reception of subsequent signals is small, the mark of each subsequent signal overlaps the previous one, forming a solid mark. Objects with better reflectivity will mark the screen larger than the objects with poor reflectivity. The latter may be completely lost in the noise of the receiver.

The sharper the antenna characteristics, the less objects will stretch across the radar imange and the greater is the correspondence between the actual sizes of the object and their representation on the radar screen.

2.2 Pulse width

The pulse width determines the size of the object mark along radiation line. If the size of the object along the line of radiation is disparagingly small (for example, a sheet of iron), the length of the mark along the scan will match the duration of a video pulse. For a more accurate reproduction of the objects is necessary to seek to reduce the duration of the probe pulses.

2.3 Beam width

Beam width in the horizontal plane determines the resolution of the direction and accuracy of directions. The antenna pattern of radar in the horizontal plane has the form of lobe elongated along the axis of symmetry and is a plot of the voltage at the receiver input of the rotation angle of the antenna in polar or Cartesian coordinates.

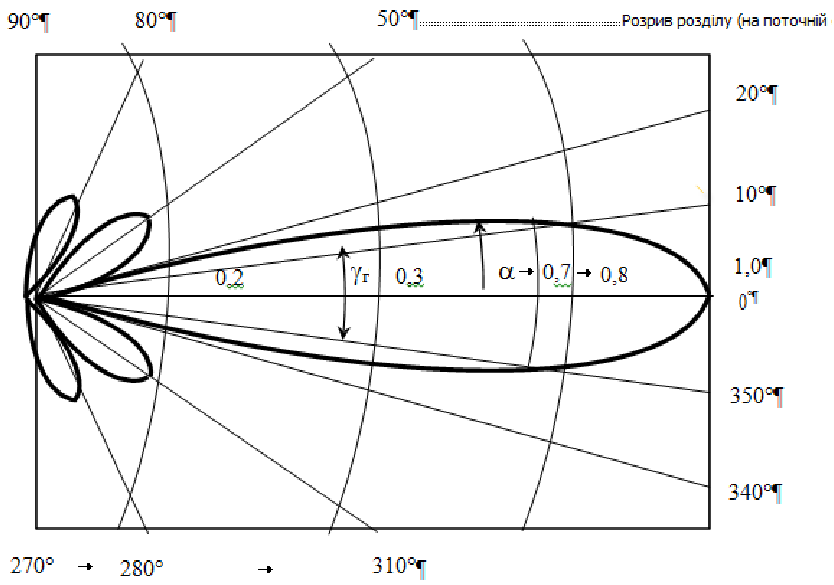


Fig. 2 The antenna pattern in polar coordinates

The numeric characteristic of antenna pattern is opening angle between the radius vectors of the input voltage of the receiver constituting the 0.707 from maximum value. If the radiation pattern is not specified by voltage but by power, its width is measured at an angle of 0.5 P_{max}.

2.4 The radiation power and receiver sensitivity

The power radiation and higher receiver sensitivity allows for the detection of objects over long distances. The level of amplification of the received signals is variable and controlled by the operator.

2.5 Pulse repetition rate, and the rotation speed of the antenna

If the the antenna will rotate during the time between pulses to an angle greater than the width of the radiation pattern in the horizontal plane, it will remain unexposed whole sectors of the area. Also, to get sufficiently stable marks on the screen, it is necessary to irradiate each object with at least 5-10 pulses. Thus, the pulse repetition frequency is closely related to the rate of rotation of the antenna beam width and to the minimum number of pulses irradiating the object. Repetition rate should be such that the time between successive pulses is greater than the time required for passage of a pulse doubled distance to a maximal far target. Usually, navigation radars have a two pulse repetition frequency, depending on the distance range

2.6 Maximal range

Maximum range (by energy condition) is:

$$D_{max} = \sqrt[4]{\frac{P_U \cdot G_A^2 \cdot S_A \cdot \sigma \cdot \lambda^2}{P_{Rmin} \cdot (4\pi)^3}}$$

Where: D_{max} – maximal range;

P_U – power on pulse, W ;

P_{Rmin} – utmost receiver sensitivity, Вт;

G_A – antenna gain;

λ – antenna gain, м;

S_A – antenna effective area, м2;

σ – effective radar cross-section (RCS) area, м2;

The gain of the antenna is determined by its effective area SA and the wavelength of the carrier λ:

$$G_A = \frac{4 \cdot \pi \cdot S_A}{\lambda^2}$$

The maximum range for direct propagation (by the geometric of Earth) is equal:

$$D_{direct} = \sqrt{h_1} + \sqrt{h_2}$$

where, h_1 – the height of the position for observed object, m;

h_2 – the height of the antenna position, m.

Minimum range of detection:

$$D_{min} = \frac{c \cdot \tau}{2}$$

where τ – the pulse width, s.

2.7 The resolution of the radar in range

Resolution station range is meant the shortest distance between two objects lying along the line of irradiation, in which marks are observed on the screen objects separately.

$$\Delta D \approx \frac{c \cdot \tau}{2}$$

2.8 The resolution of the radar in azimuth

Under the resolution in the direction of the station meant that the angular distance between two equally distant objects, in which their marks are observer for separately. The resolving power of the station in the direction primarily depends on beam width.

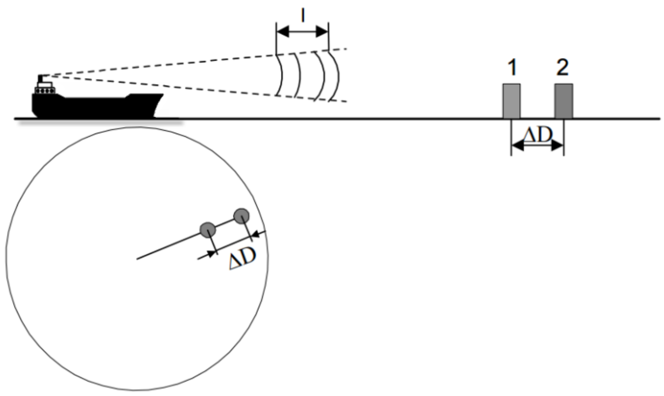


Fig 3. The resolution of the radar in range

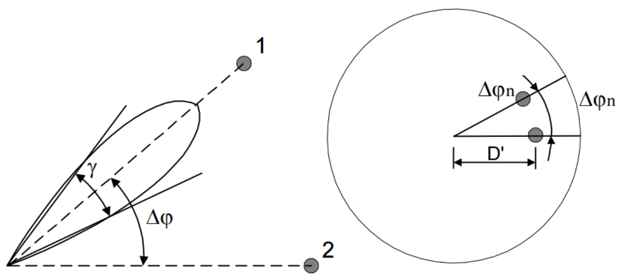
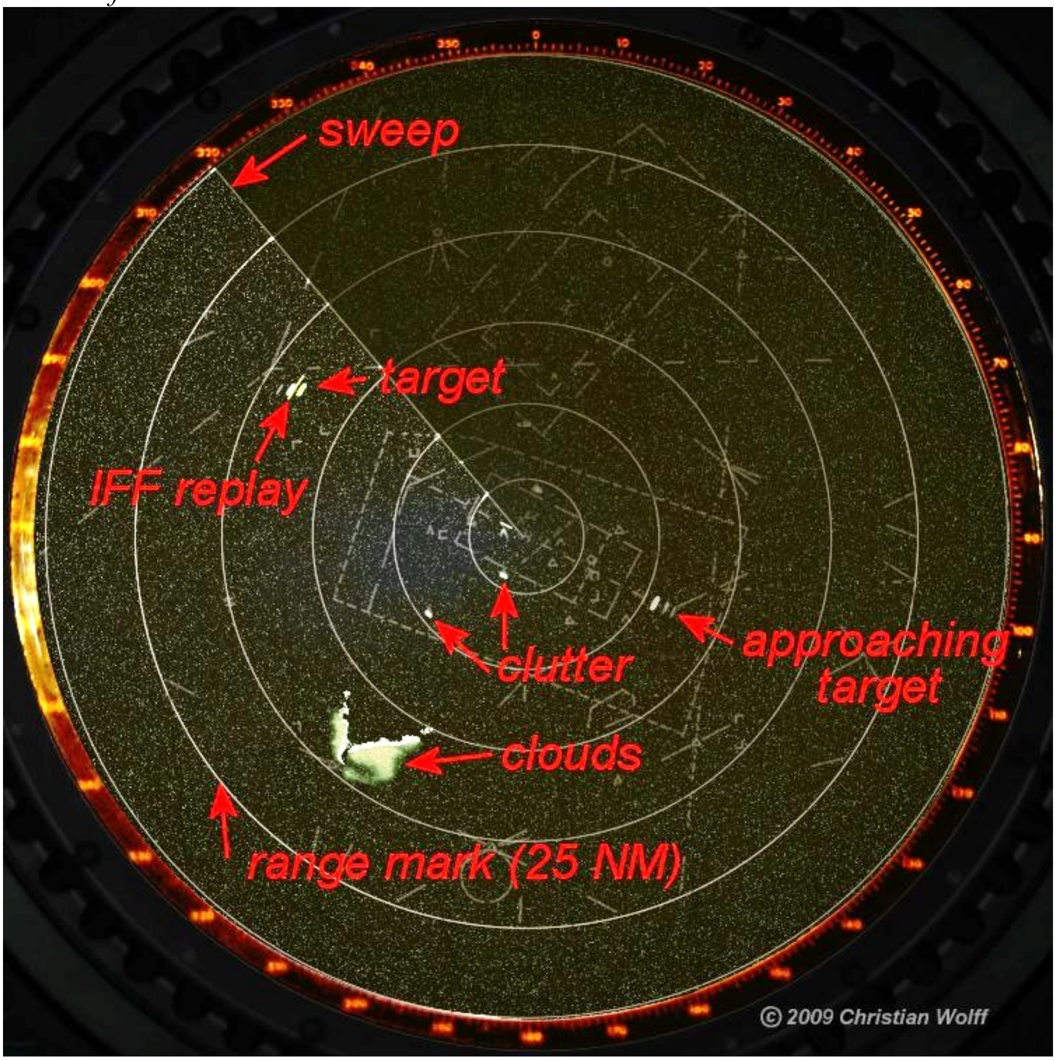


Fig 4. The resolution of the radar in angle (azimuth)

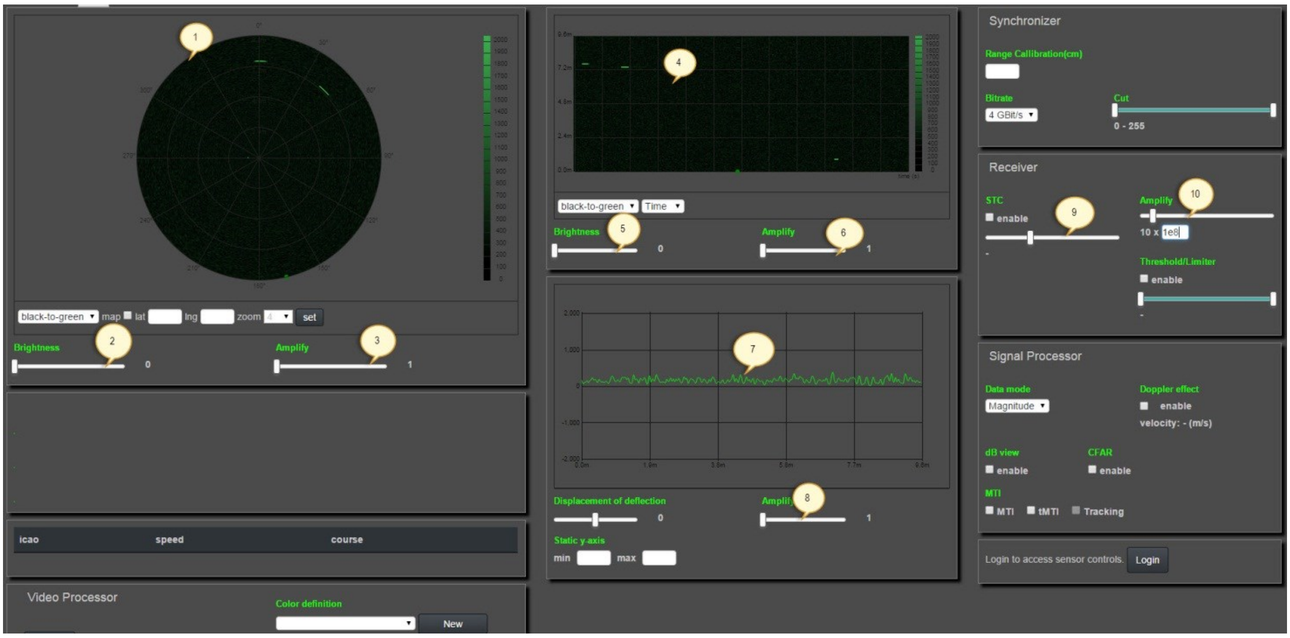
Example screen of PSR



Source: www.RadarTutorial.eu by Christian Wolff

3 BASIC CONTROLS OF THE PSR SIMULATOR

3.1 Elements of the radar windows for in the Controller Work Position CWP



Where

1 –PPI – plan position indicator;

2 – Brightness slider for the PPI;

3 – Amplify slider for the PPI;

4 – A-scope – displays power of reflected signal vs range;

5 – Brightness slider for the A-scope;

6 – Amplification slider for the A-scope;

7 – B – scope visualisation with range vs angle Cartesian coordinates;

8 – Amplify slider for B-scope;

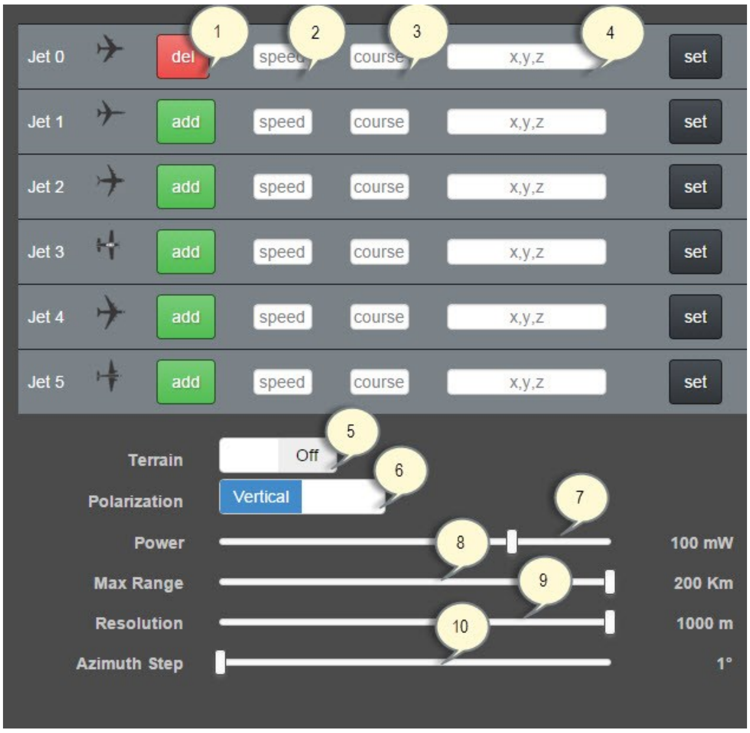
9 – Sensitivity Time Control (STC) checkbox and slider controls;

10 – Amplify controls (slider and multiplier).

The controller work position ("CWP") allows gives the learners the view point of a controller.

SkyRadar allows operating more than 1000 concurrent CWPs, where students do independent manipulations. The CWP allows setting filters, amplification and manipulation of the received QI signal. However it has no influence on transmitter and antenna. Those manipulations need to be done in the Pseudo Pilot Position.

3.2 Elements of supervisor window for Pseudo Pilot Position control



1 – button for adding/removing of aircraft

2 – speed control field

3 – course control field

4 – current position field

5 – adding/removing reflection from environment

6 – polarization type

7 – power switch

8 – maximal range switch

9 – range resolution switch

10 – angle resolution switch

To set up the airspace, please use the pseudo pilot position (“**PPP**”). You can define the position per aircraft (1, 4), the speed (2) and the course (3). In the current release, all aircraft models have the dimensions of the Boing 747.

Setting up the airspace also implies to define whether there is reflection for the terrain or not (5)

Apart from placing the aircrafts into the sky (and defining position, course and speed), the PPP allows to configure the radar.

A maximum of 8 PPP can be opened concurrently. Exceeding that will significantly slow down the process.

4 EXAMPLES AND CHARACTERISTICS OF PULSE RADARS ILLUSTRATED WITH THE PSR PULSE SIMULATOR

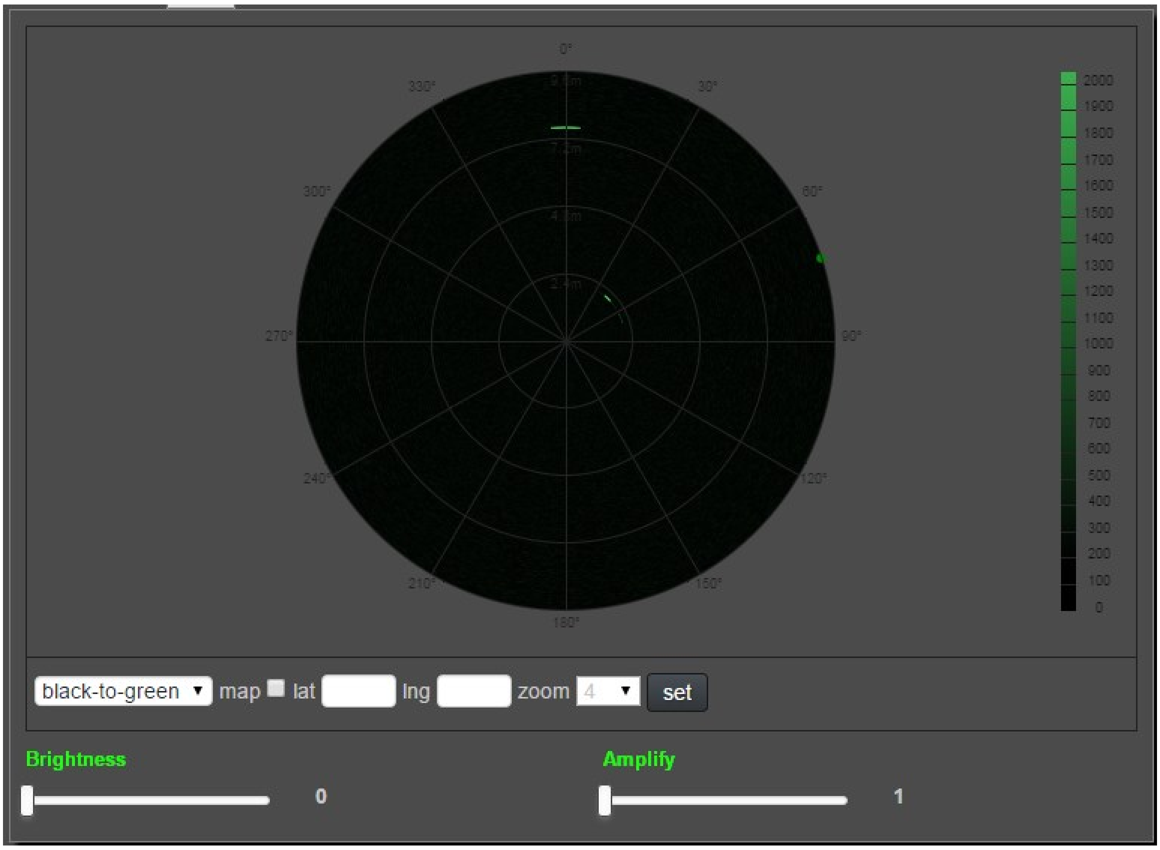
A pulse radar is a radar system that determines the range to a target using pulse-timing techniques, and uses the Doppler effect of the returned signal to determine the target object's velocity. It combines the features of pulse radars and continuous-wave radars, which were formerly separate due to the complexity of the electronics.

Pulse systems measure the range to objects by measuring the elapsed time between sending a pulse of radio energy and receiving a reflection of the object. Radio waves travel at the speed of light, so the distance to the object is the elapsed time multiplied by the speed of light, divided by two - there and back.

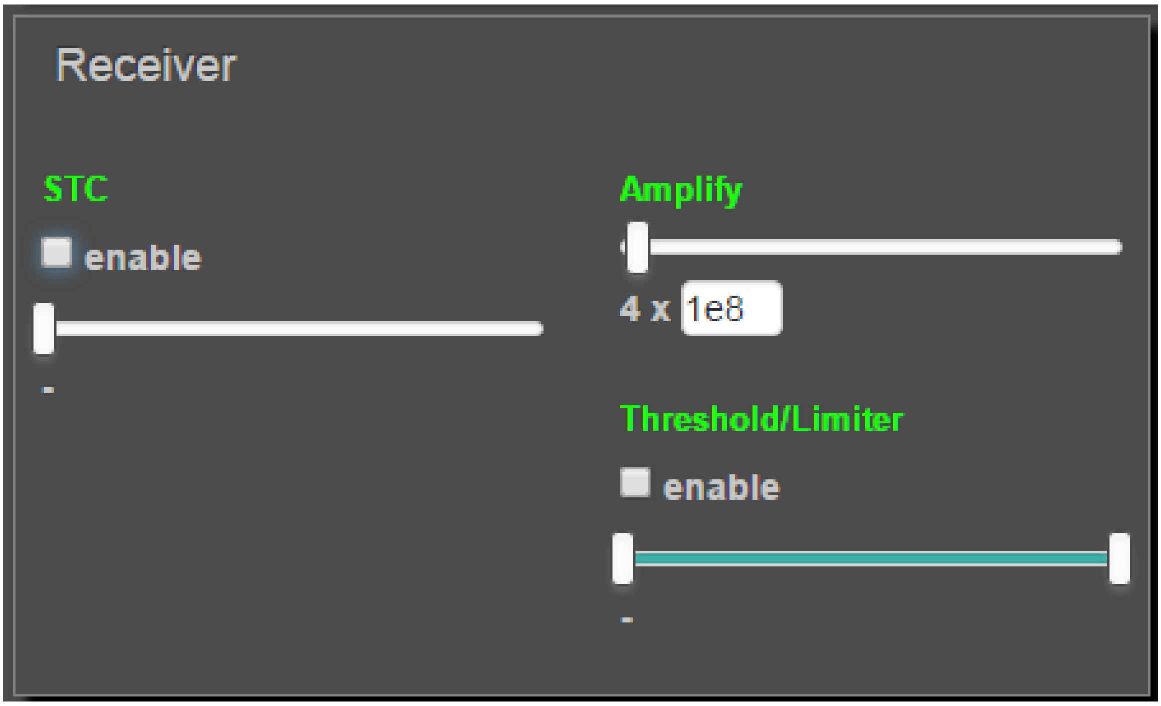
For further reading, please refer to the chapter on Pulse Radars in www.RadarTutorial.eu

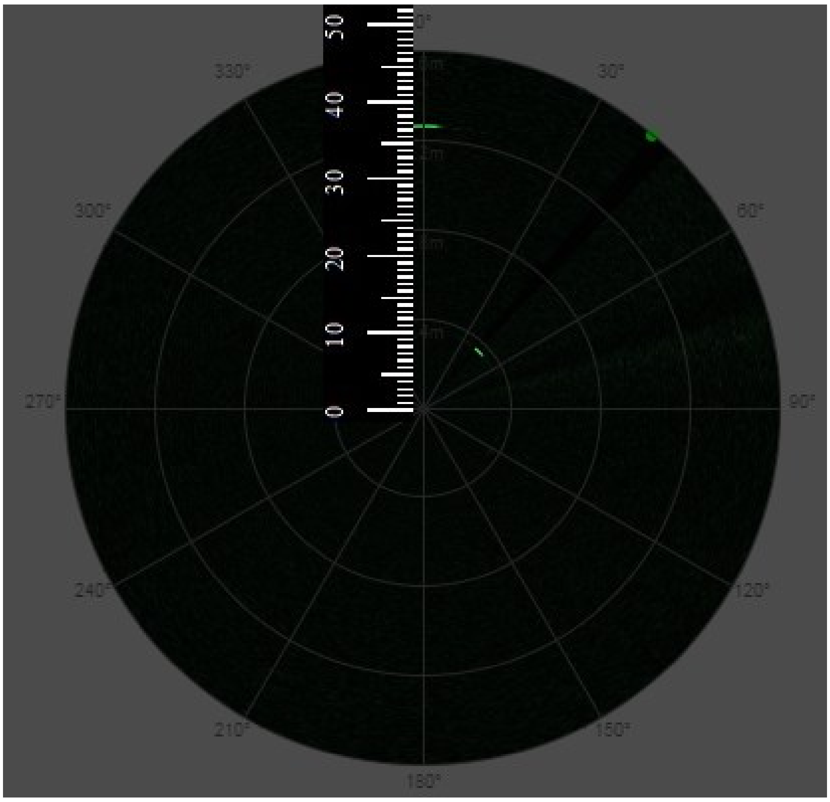
4.1 Determination of the distance and direction between radar and aircraft as well as between aircrafts

Please open a CWP



Please set the amplification on 4*108 . We type 1e8 and then set the factor 4 with a slider.





Make some measurements:

RD=47mm,

RonPPI=37 mm,

Rmax=200 km,

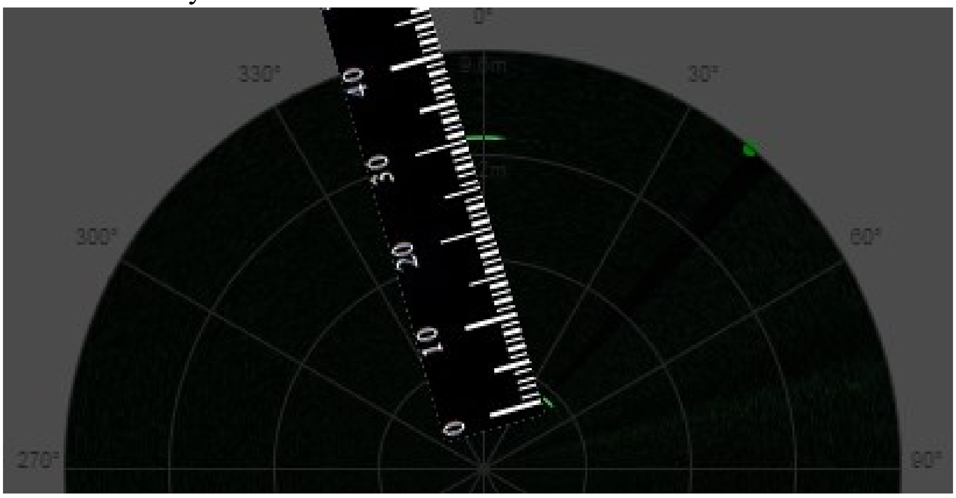
And calculations:

D=200000*37/47=157,5km

The azimuth angle can be obtained from circular scale:

Az=0 degree;

In the same way the distance between two aircrafts can be obtained



The scale M_D will be as in previous situation:

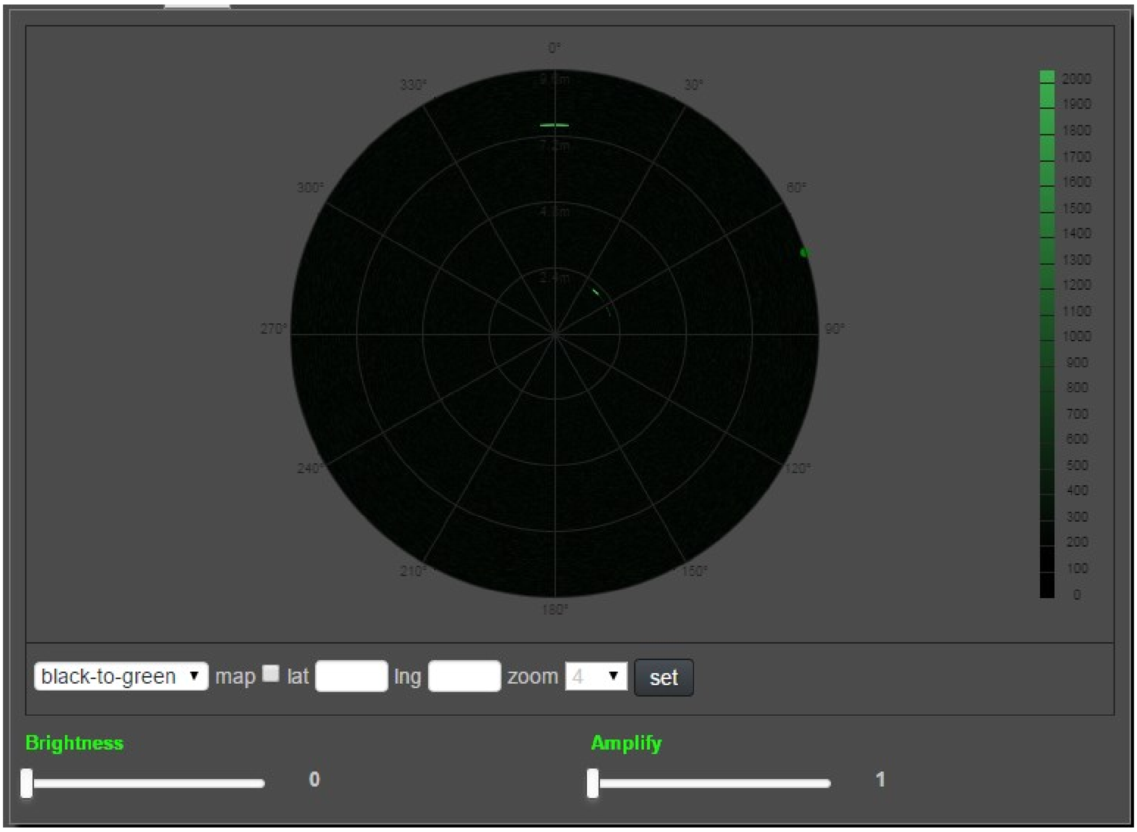
M_D=200000/47=4250m in mm

R_{onPPI}=30 mm,

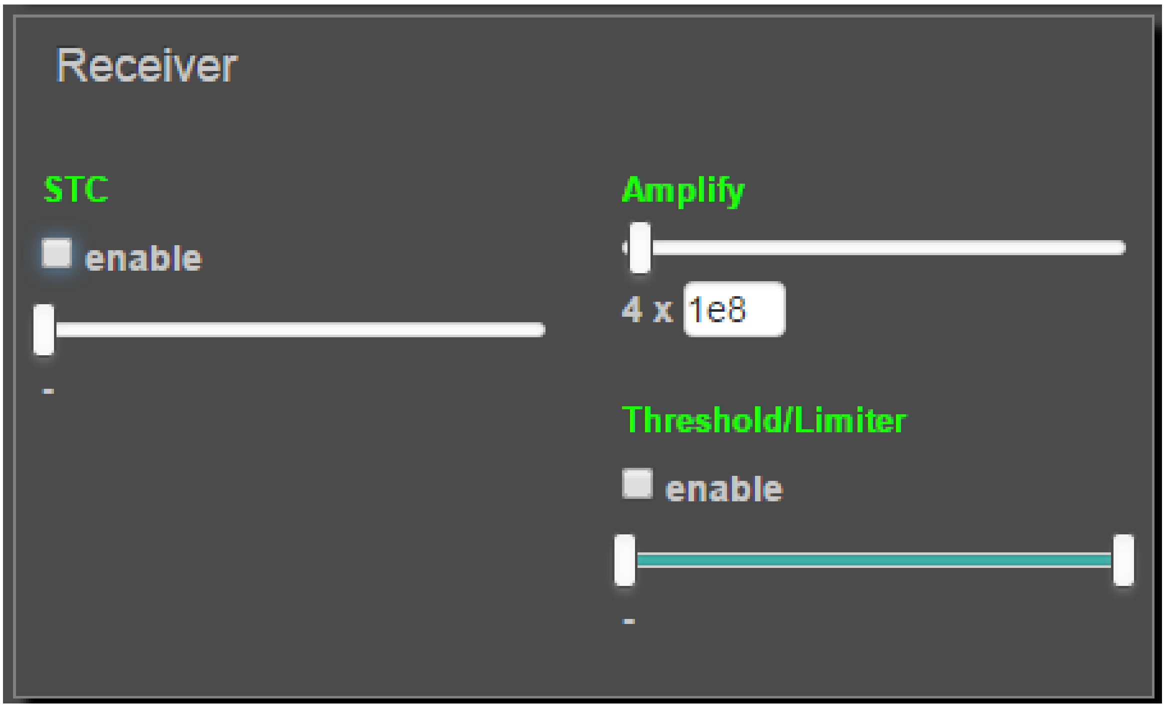
D=4250*30=127,5 km

4.2 Working in conditions of interference from terrain

Start working in an idealized condition with no terrain reflections and use the parameters : below.

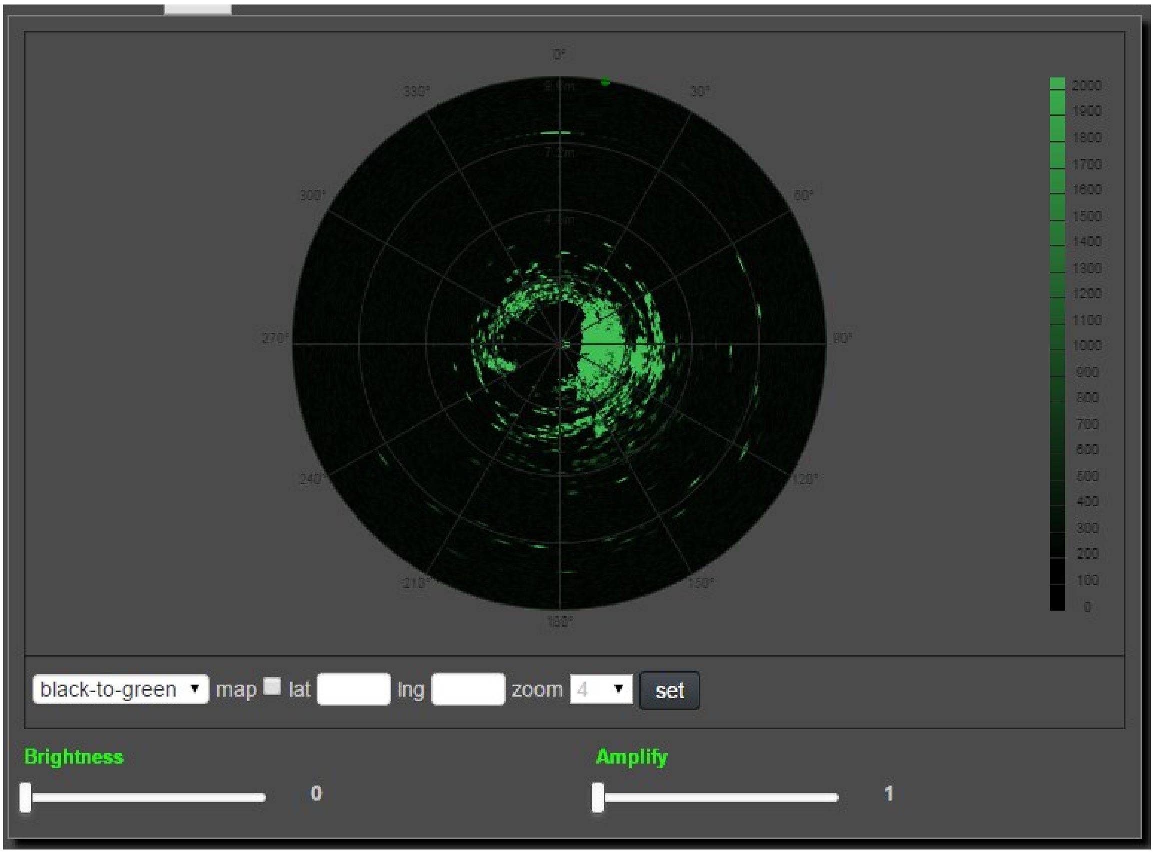


In the configuration panel on the right side, you can configure filters and amplification. Please use the configuration below:

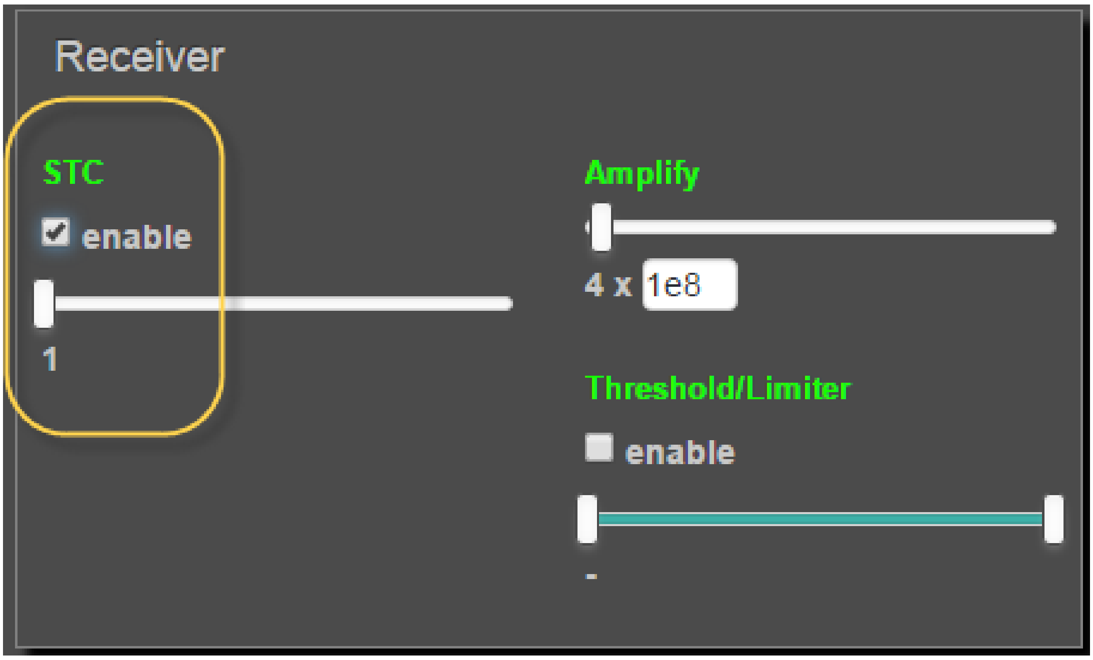


Now the operator of the PPP should add *terrain*

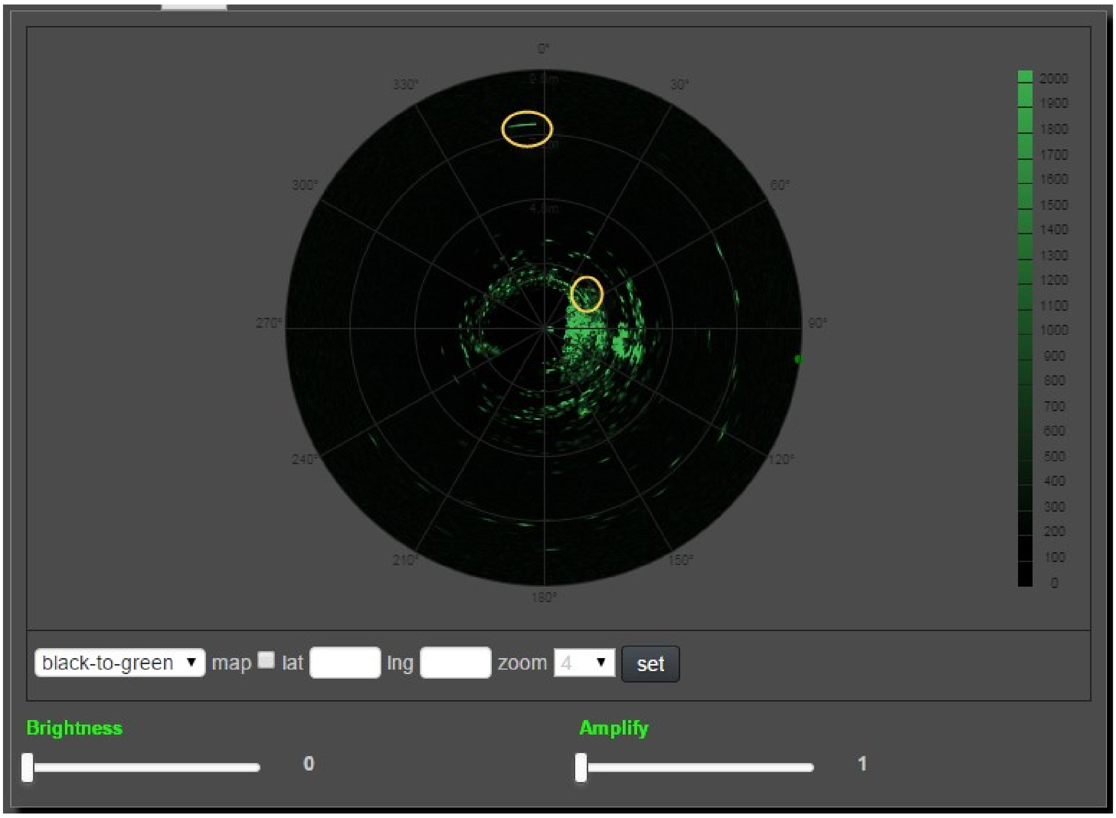
You should get the following PPI image.



Use *STC* to decrease or even eliminate of terrain interference



Try to identify the aircrafts.

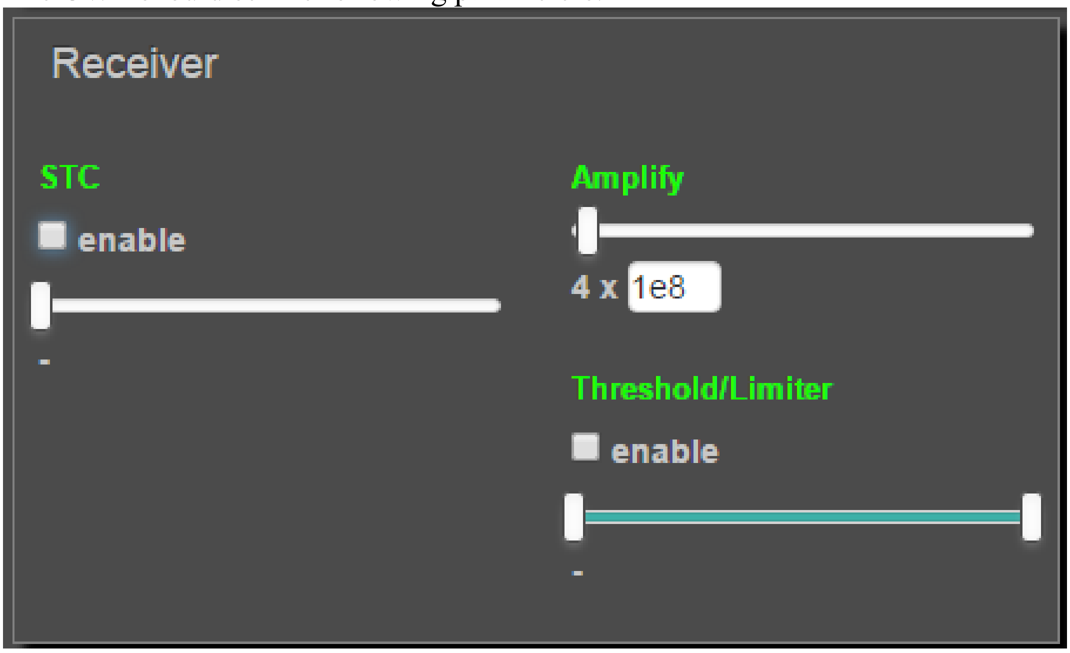


4.3 Accomplishing the ideal resolution

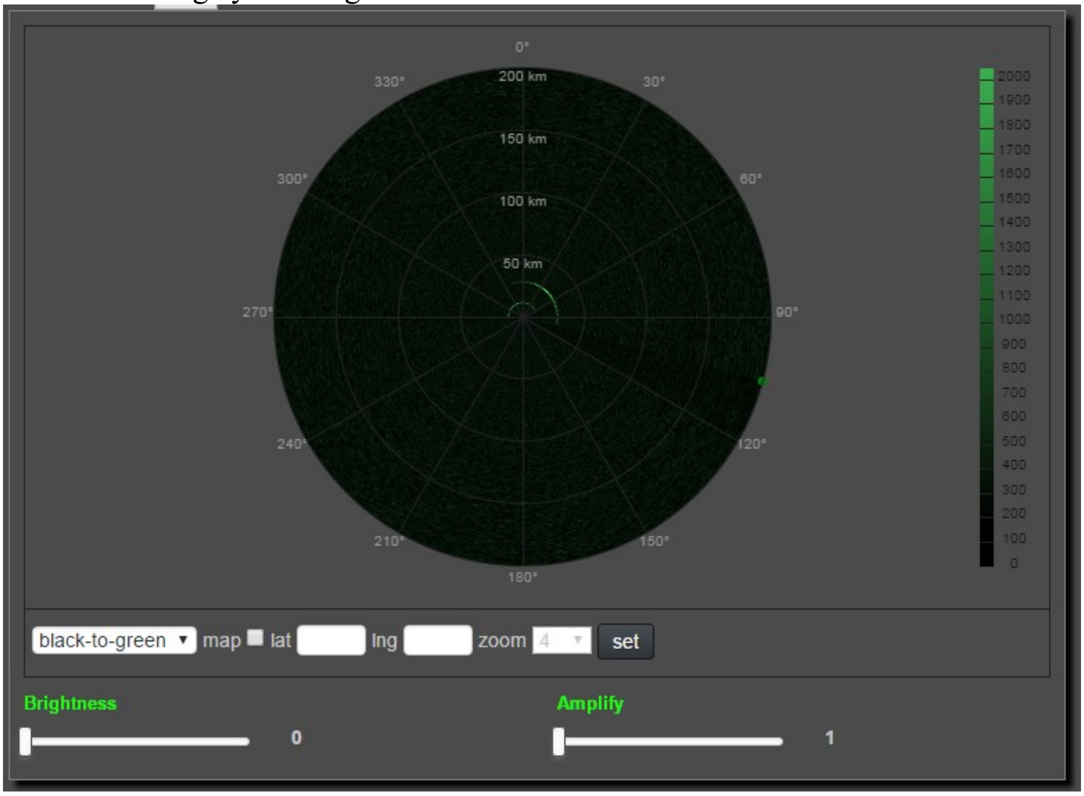
Start optimizing with the closest aircraft to the radar.

The PPP should set the following parameters.

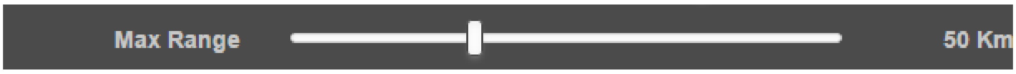
The CWP should set the following parameters:



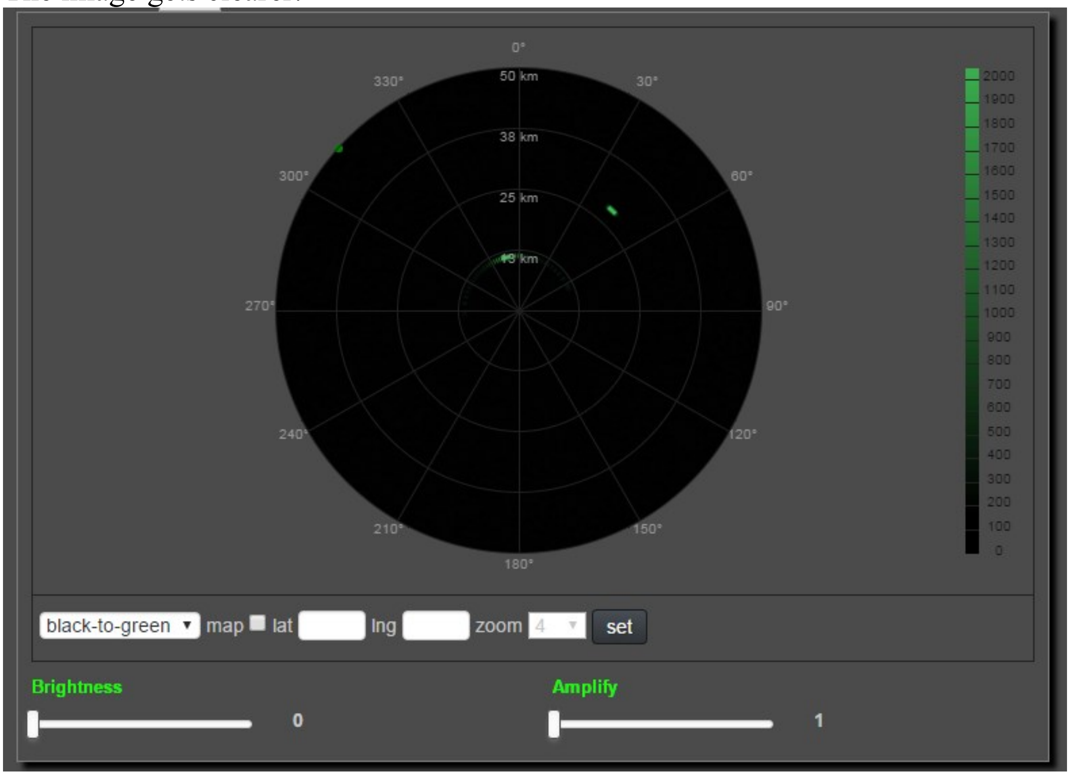
This is the image you will get in the PPI



To see more details we need ajust only the maxrange:

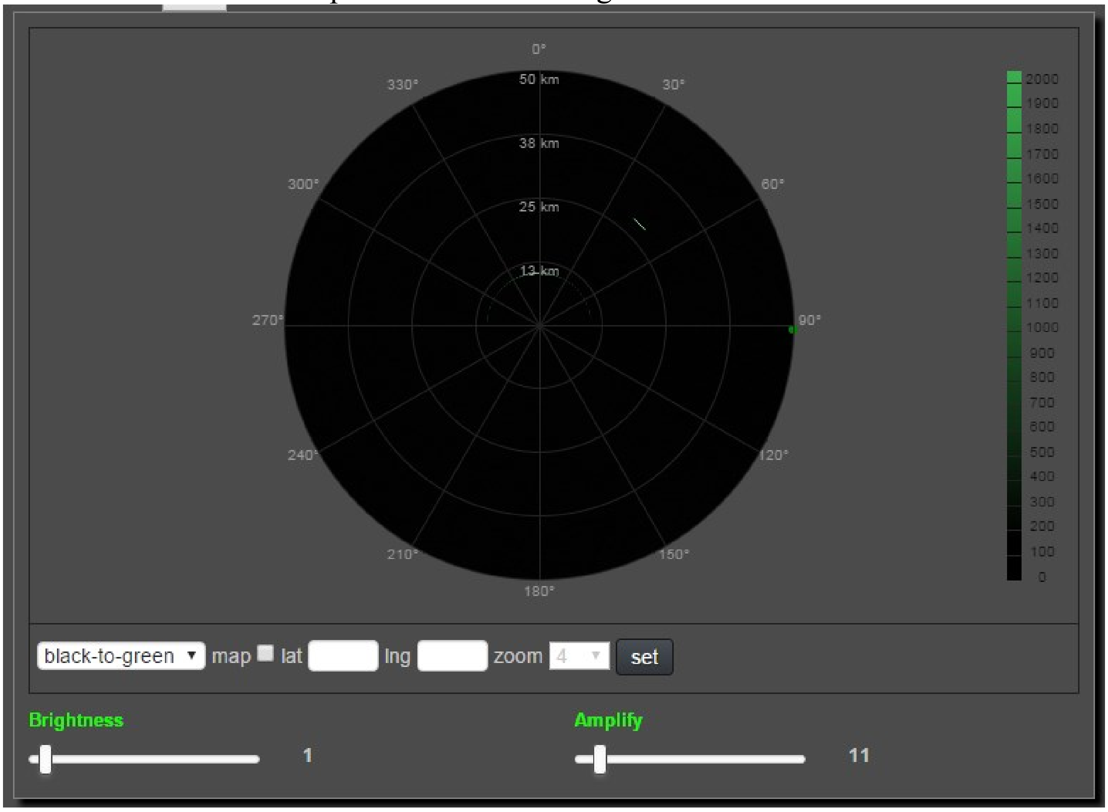


The image gets clearer:



The *range resolution* of the transceiver can be changed in the PPP to obtain more detailed results.

The PPI in the CWP will produce the following results:



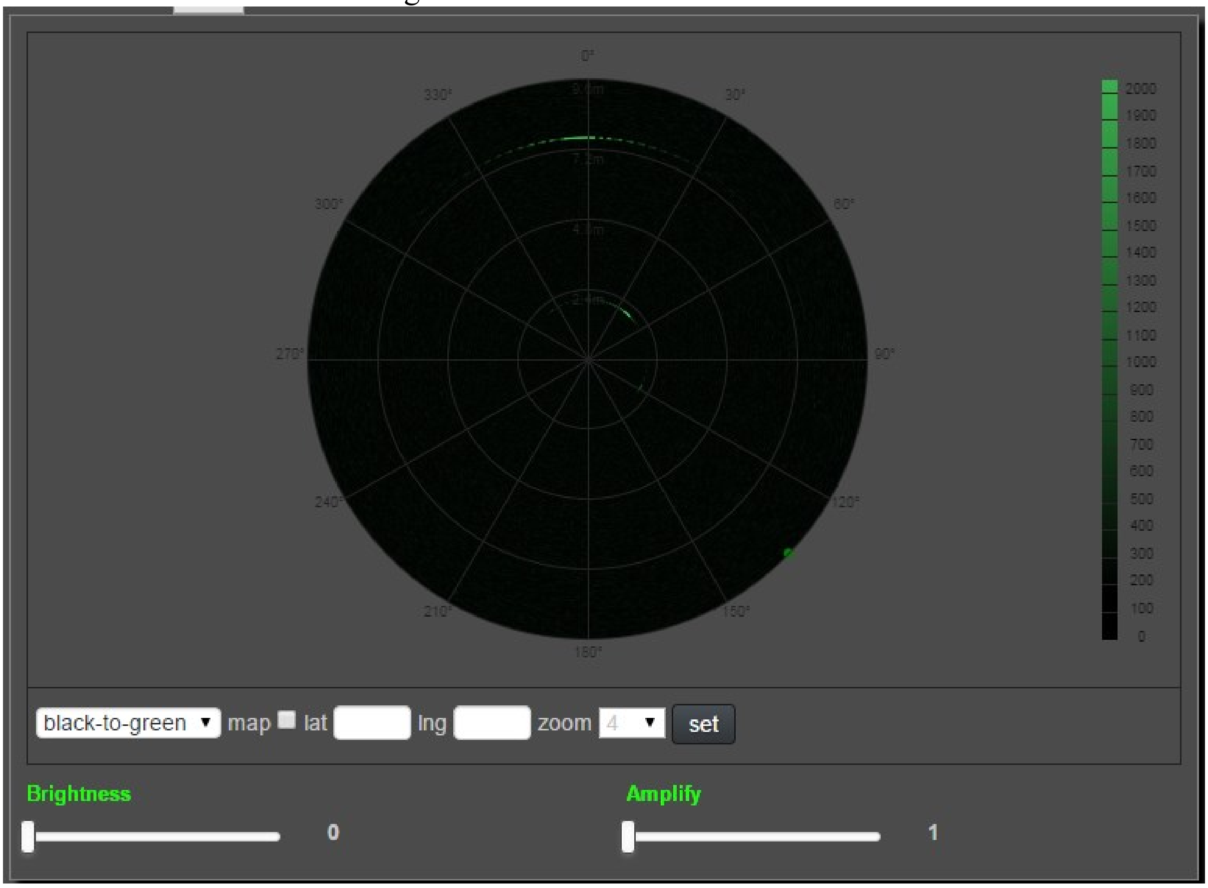
Changing the *maxrange* property will change only the display resolution, as it dimensions the axis. The resolution property of the scanned radar image will change when changing the *radar resolution*.

4.4 Effect of the signal power and noise to radar performance

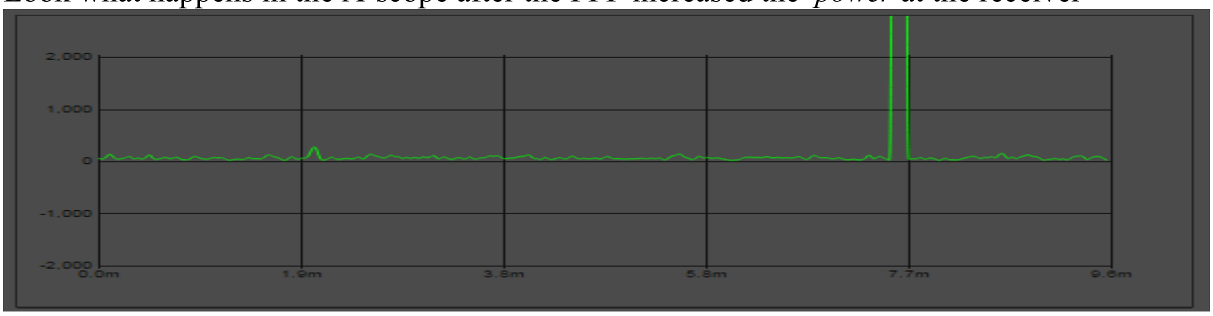
Let us now analyze the effects of signal power and noise on the radar performance.

The PPP should set the following maximum power level:

The PPI will show the following:

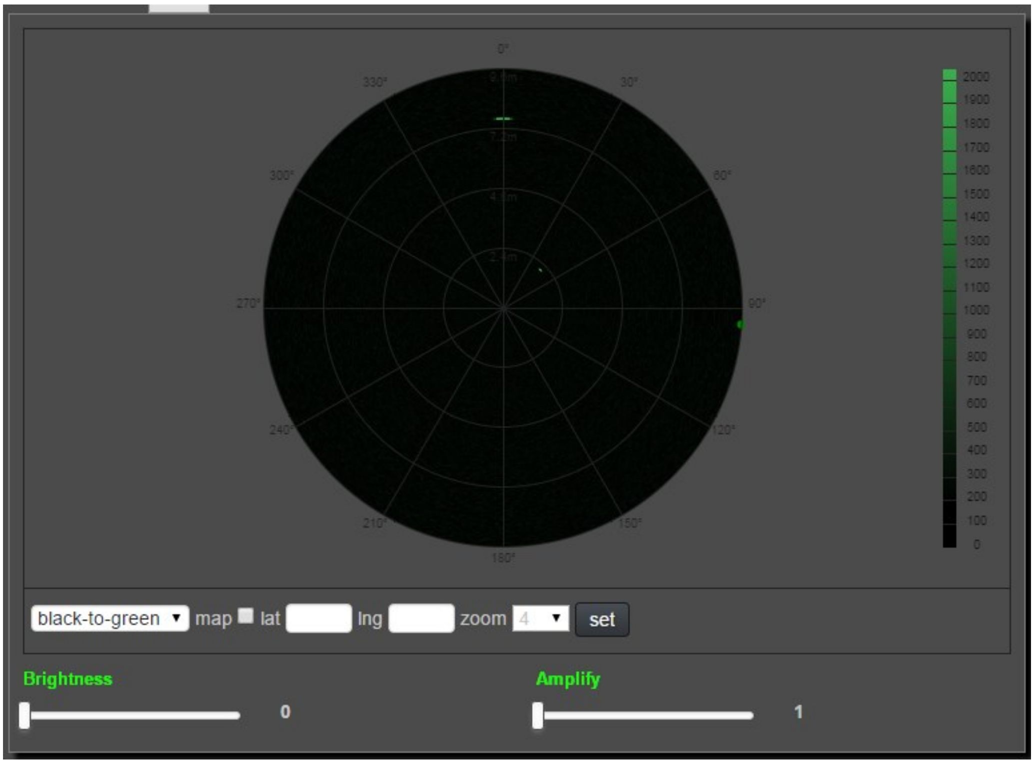


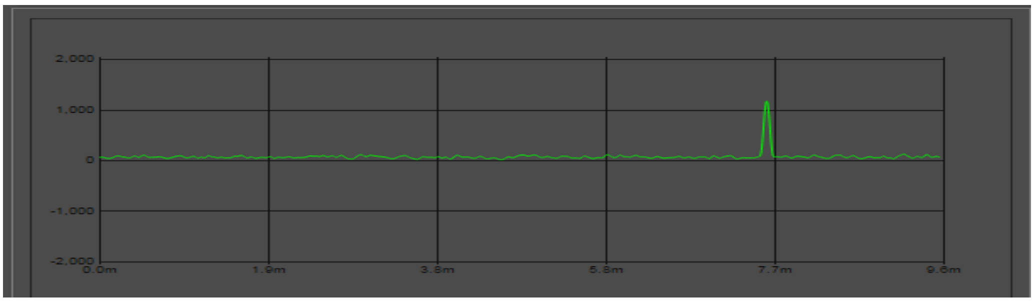
Look what happens in the A-scope after the PPP increased the *power* at the receiver



Let the PPP change the *power* level to m inimum

Look what happens to PPI and A-Scope:

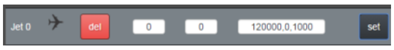




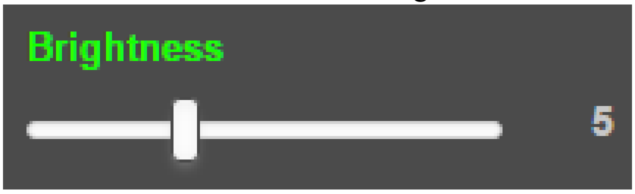
4.5 RCS fluctuation and using polarization changing for decreasing of effect

When a target rotates, RCS can change. It is one of the causes for target fluctuation. In the worst case target even can be lost. Let us simulate this situation by changing the course angle

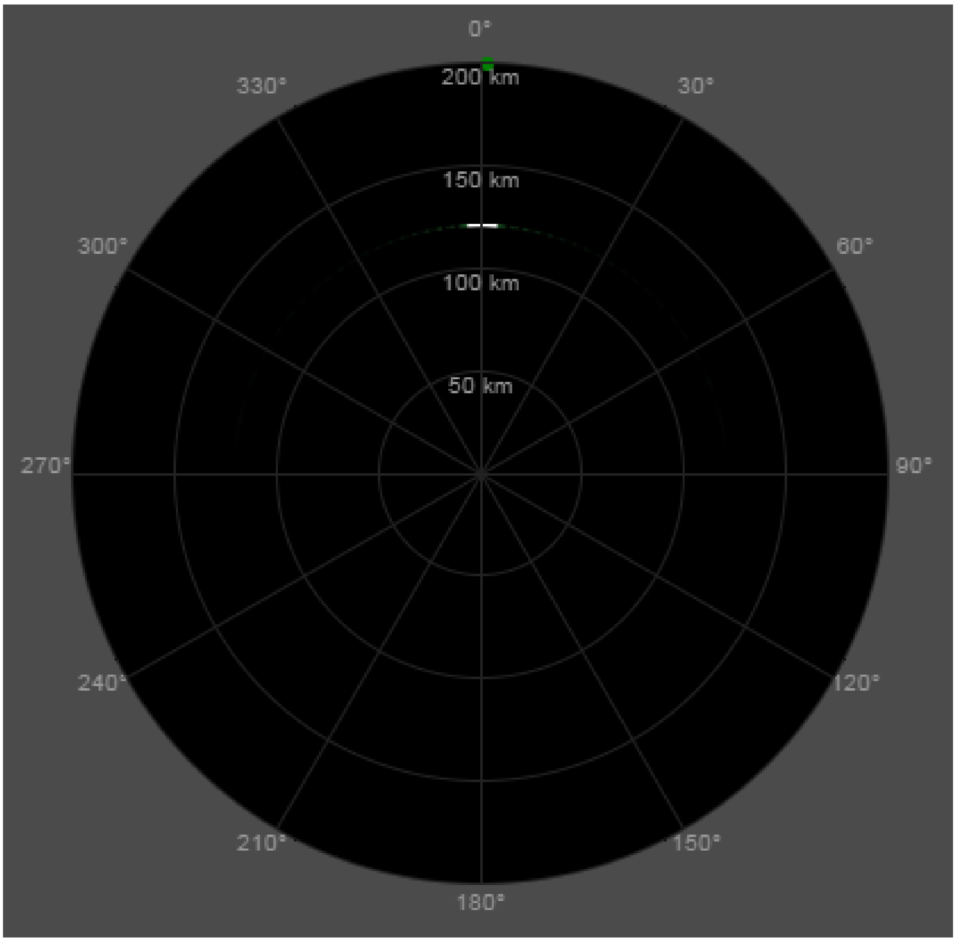
The PPP should set the following:



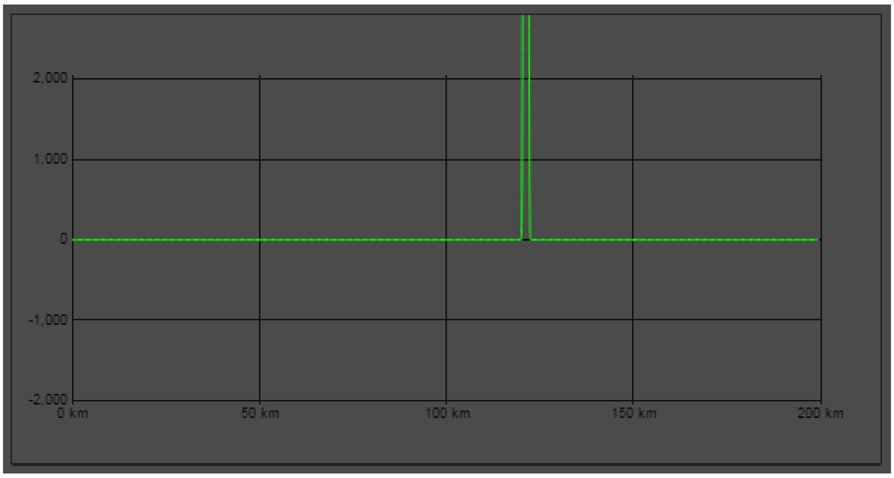
The CWP should set the following:



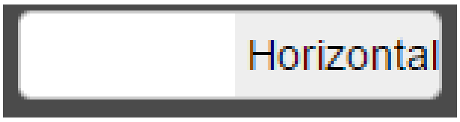
Look in the CWP at the PPI in this configuration



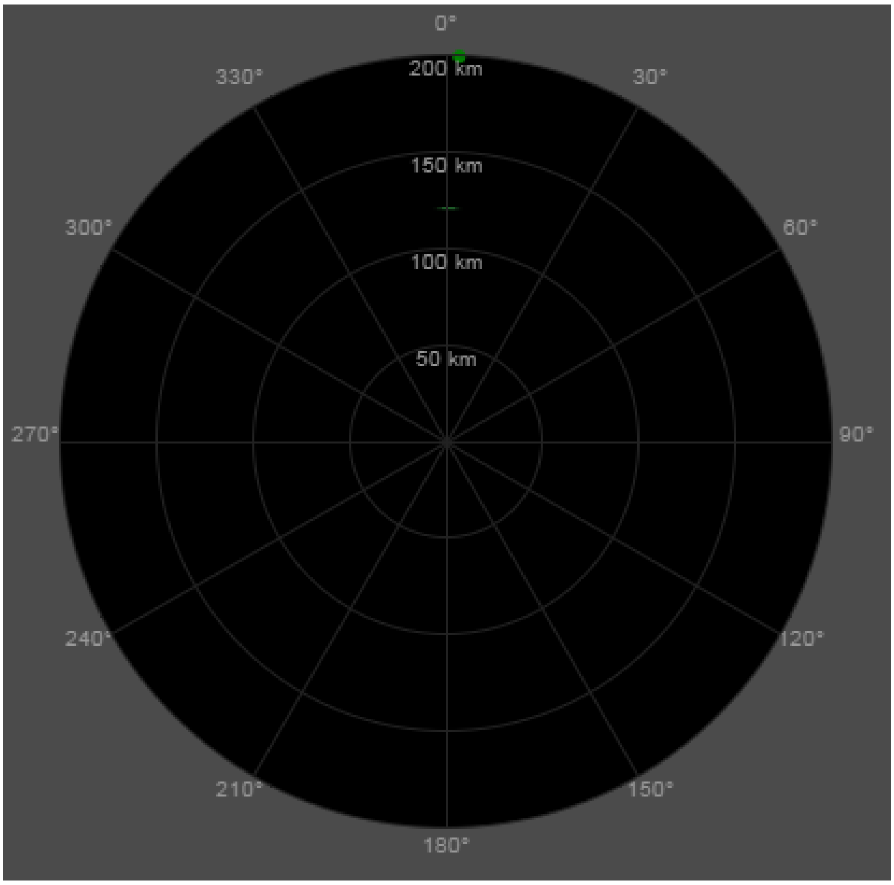
You see the high impulse in the A-scope.

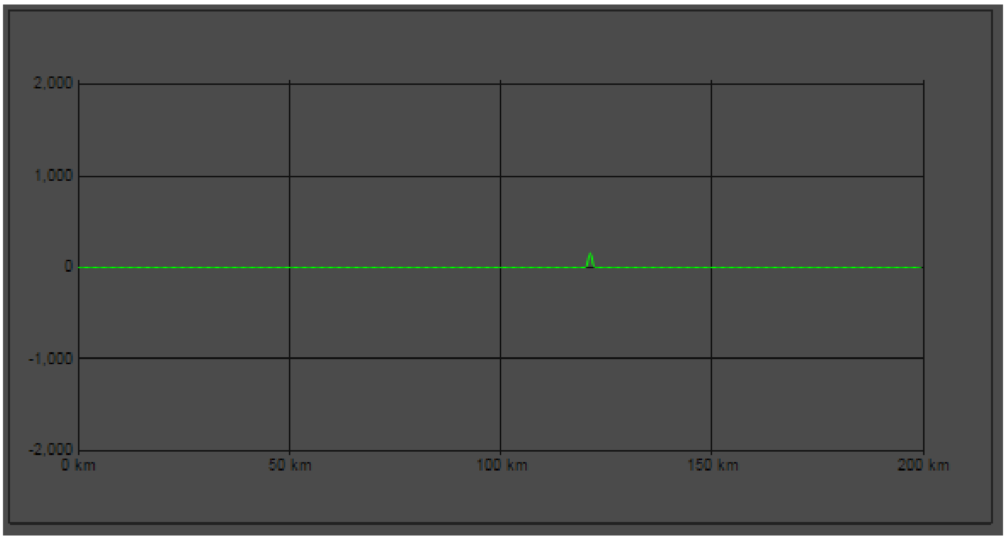


To eliminate this effect we can set the polarization to horizontal



Now in the CWP look at the effect on the PPIand the A-scope



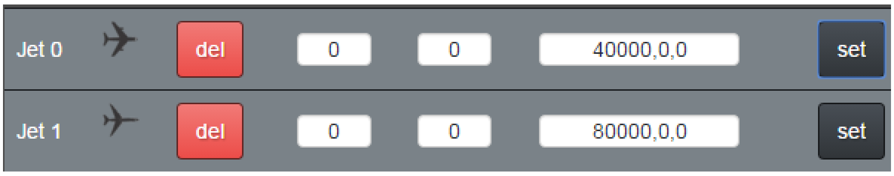


In particular, the effect of the of the change of polarization manifests in the A-Scope.

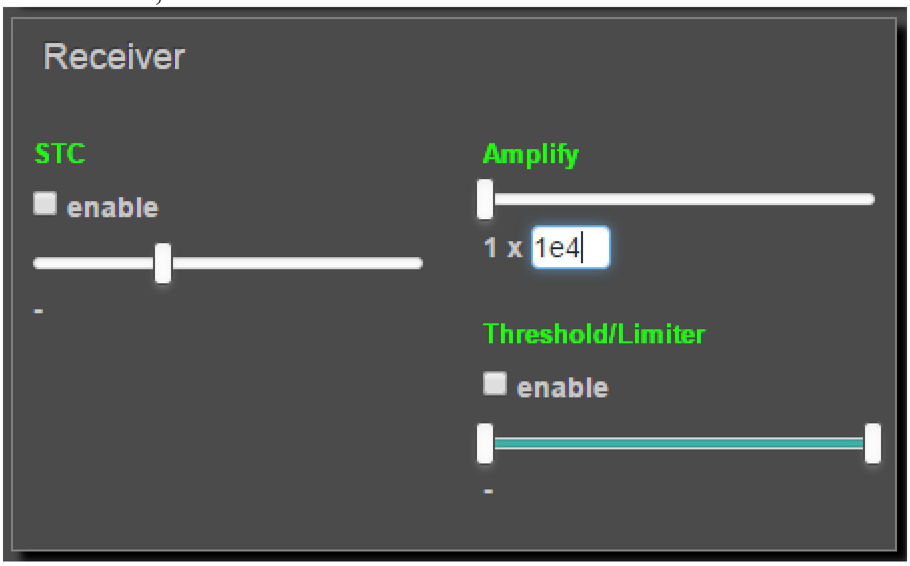
4.6 Signal attenuation

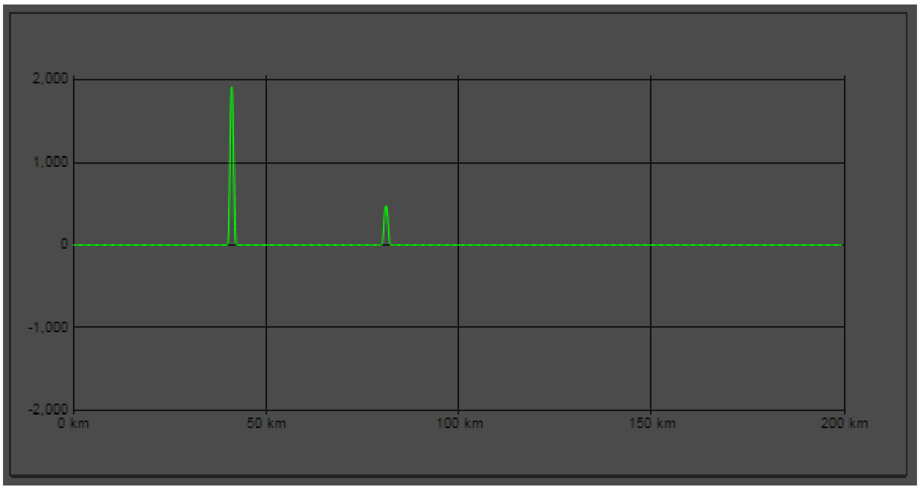
Signal power attenuates over distance. You can simulate this when placing the same object at two distances along the same alignment.

Have the PPP set the following airspace:



In the CWP, set the Receiver as follows:





Look at the attenuated signal in the A-scope.

4.7 TASKS FOR SELF-PACED LEARNING

Based on the flight conditions generated by a supervisor in terms of interference from terrain to determine:

1. The current position of the aircraft

2. Check the safety of all aircraft by determining the distance between them

3. Approximately assess the levels of signals reflected from the aircraft depending and the distance to and between them, as well as the signals reflected from the surrounding objects and radar noise.

Make conclusions about the level of the signal/obstacle and the signal/noise ratios.

5 EXAMPLES AND CHARACTERISTICS OF CW RADARS ILLUSTRATED WITH THE CW (DOPPLER) SIMULATOR

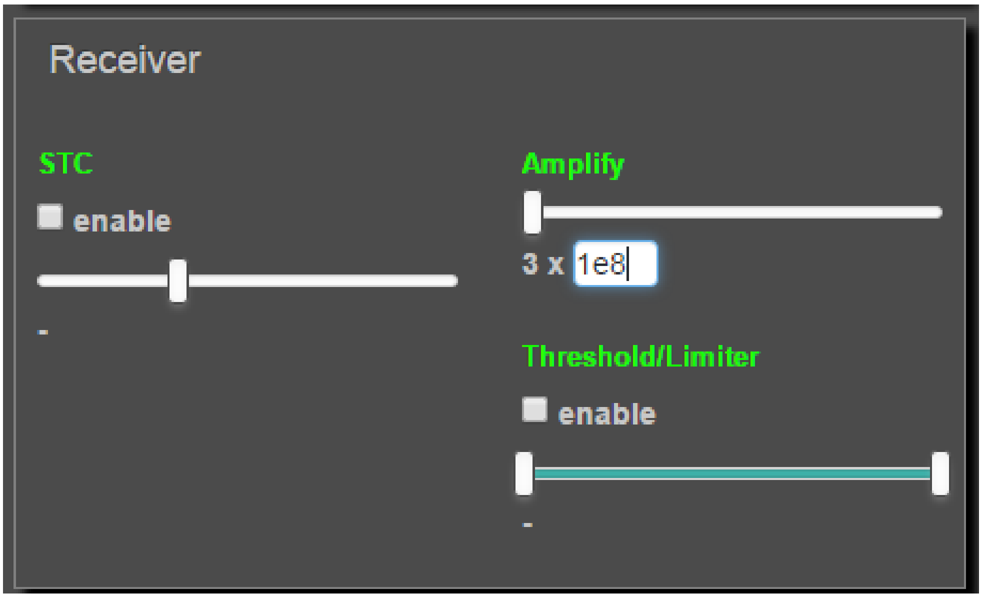
The continuous wave radar is a type of radar system where a known stable frequency continuous-wave radio energy is transmitted and then received from any reflecting objects. The continuous-wave (CW) radar uses the Doppler effect, which renders the radar immune to interference from large stationary objects and slow moving clutter.

Further Reading: the chapter on Continuous Wave Radars in the www.RadarTutorial.eu

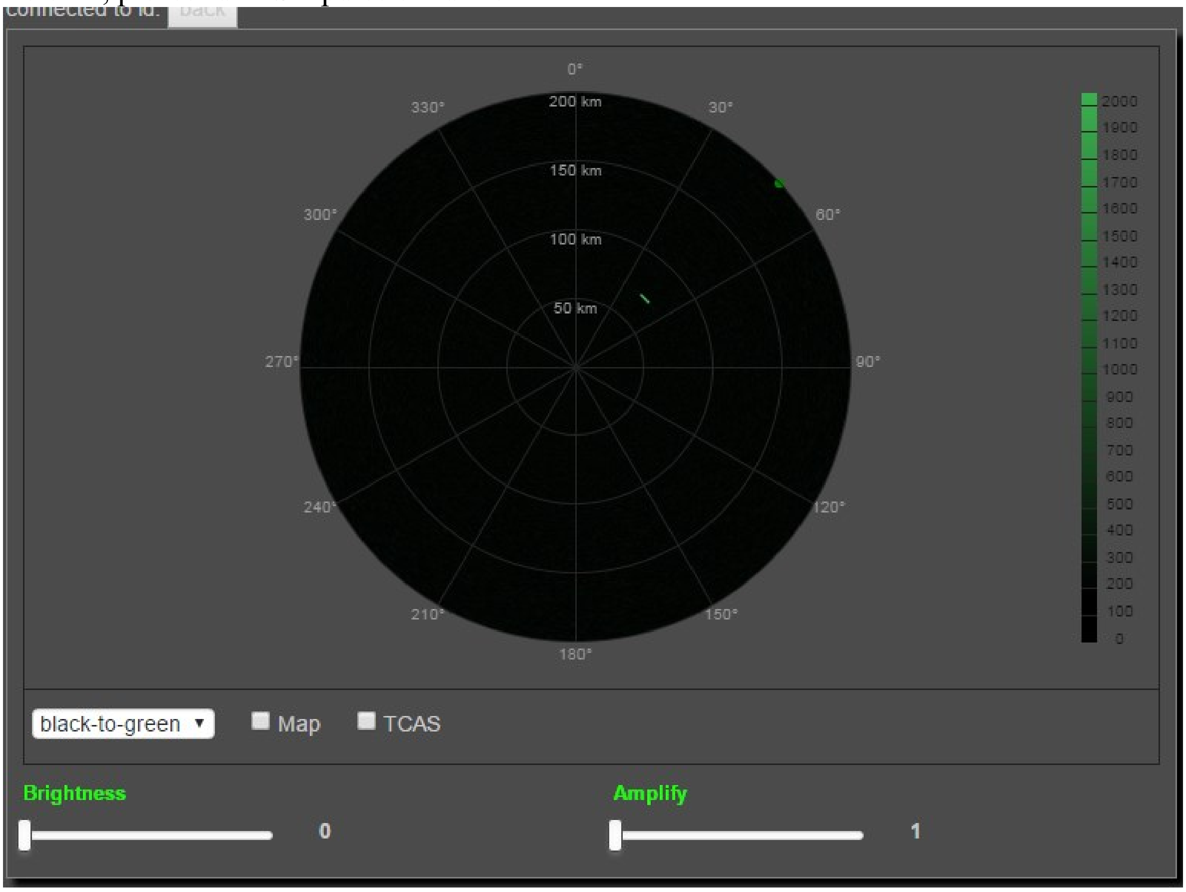
5.1 Using the Doppler radar to discriminate the targets by the speed

Have the PPP set the airspace and the transmitter as follows:

In the CWP, please set the receiver as follows:



To start, please run PSR pulse simulator

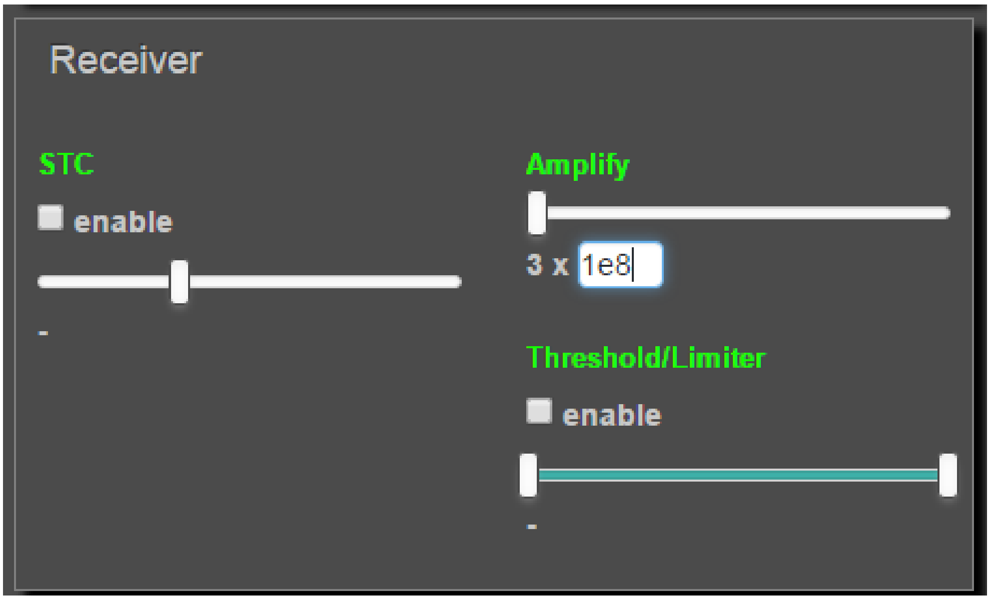


Both aircrafts are overlapped in one position.

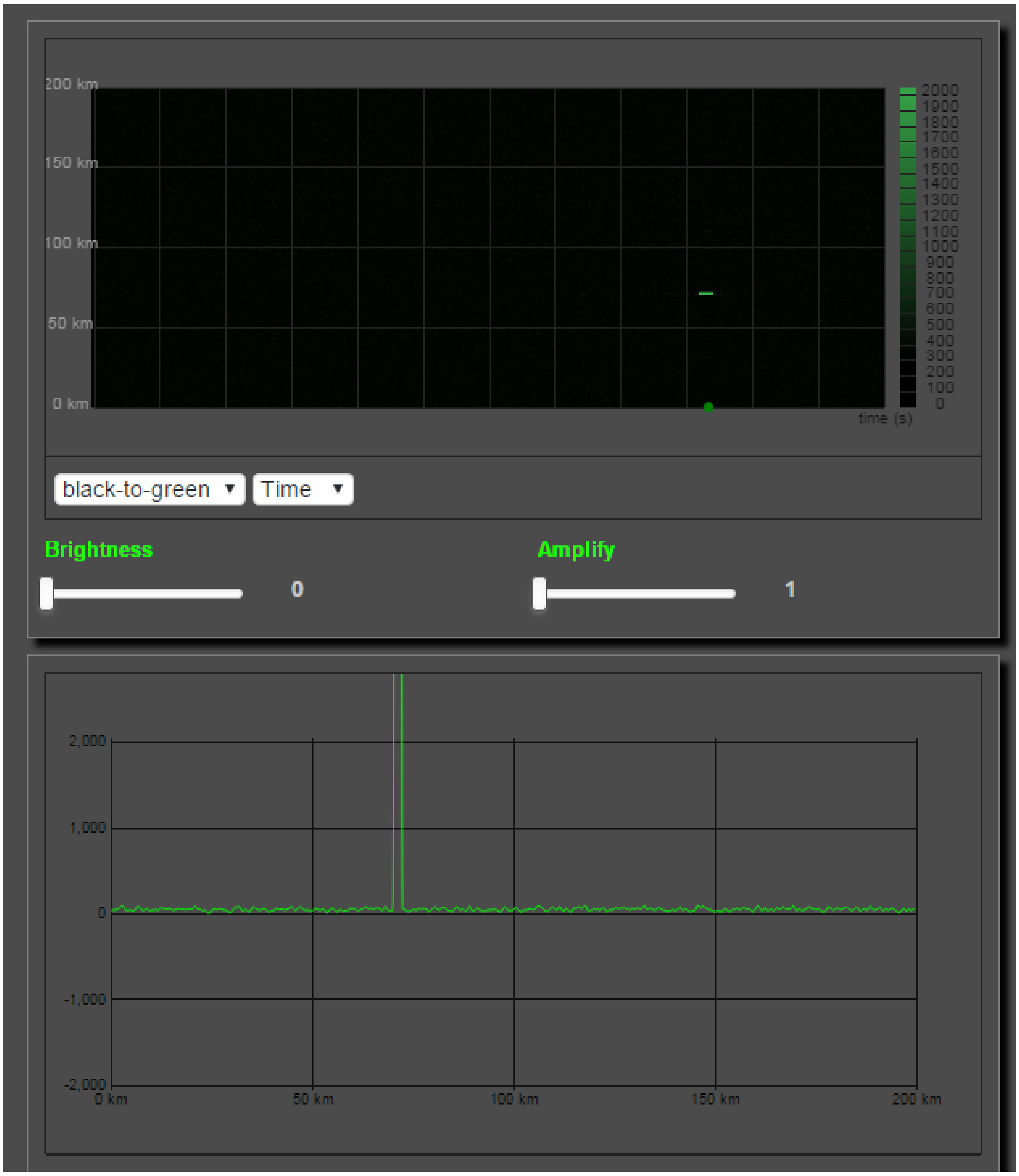
Therefore now look at the CW simulator while using the same parameters.

In the CW simulator, have the PPP set the following:

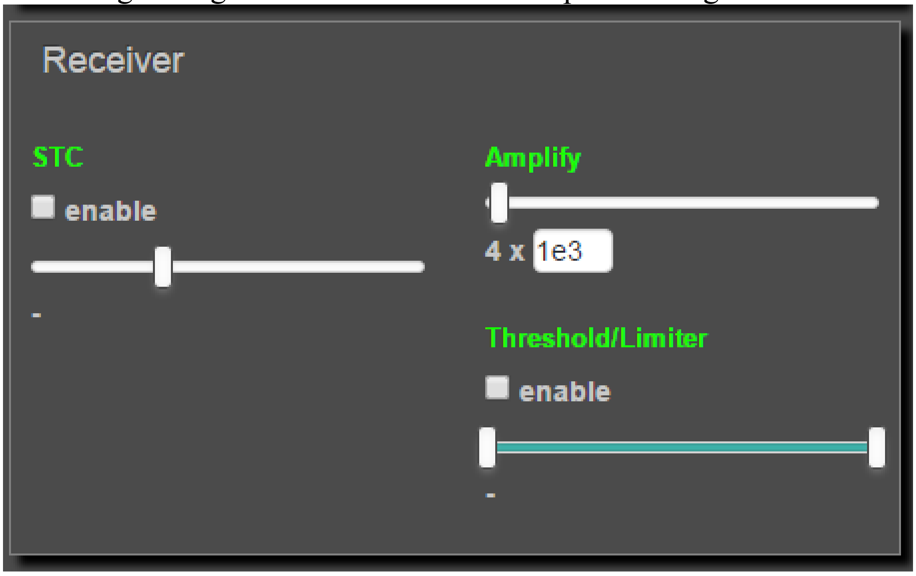
In the CWP set the following:



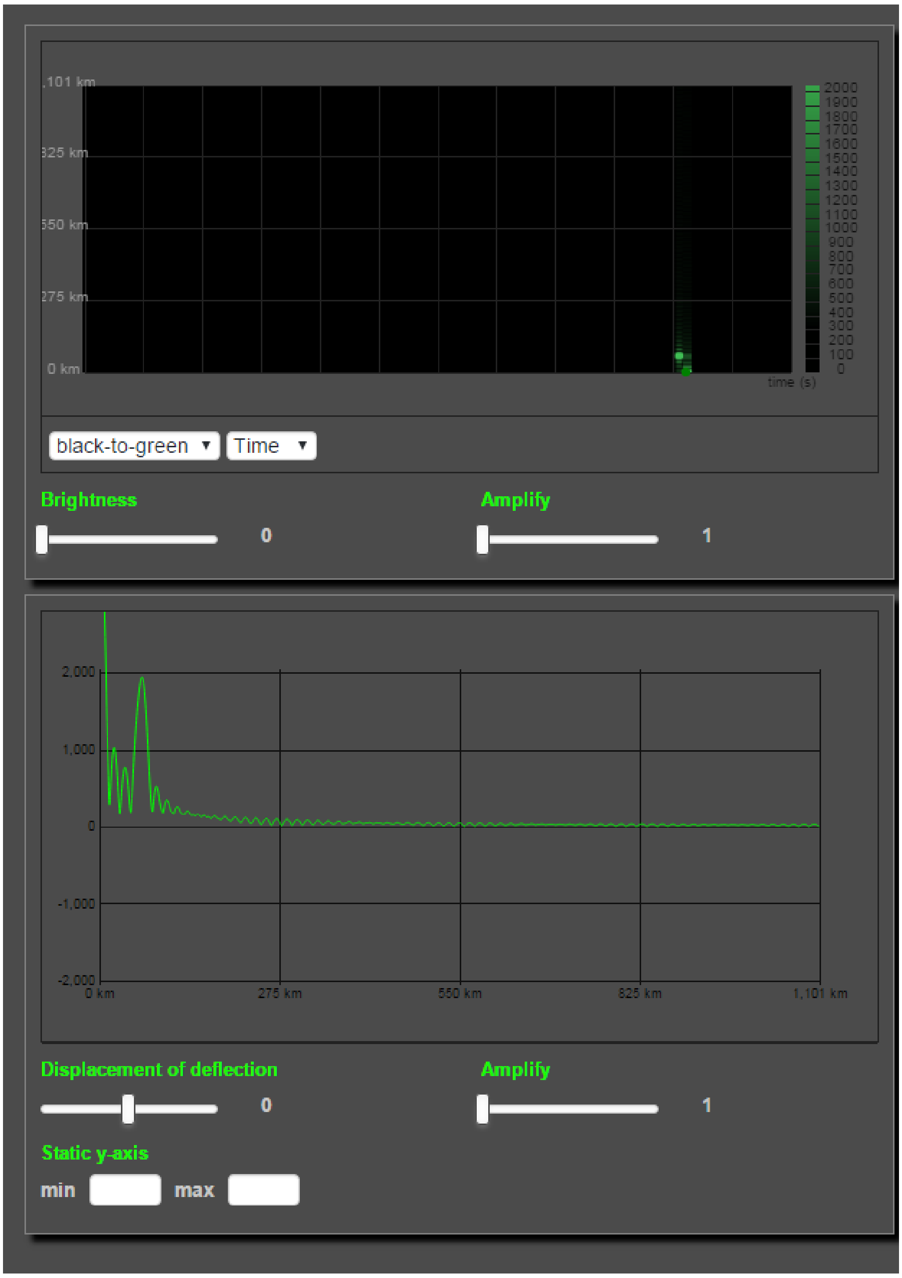
The CW simulator will show the following image:



Now do the following settings. Please notice the the amplification goes down to 4 x 1E3



Look at th e B-Scope and the A-scope and see how well you can differentiate the targets.



Now we can see both targets even they positioned in same resolution volume. Later we pick up this example again to illustrate the advantages of the FMCW radar

6 EXAMPLES AND CHARACTERISTICS OF FMCW RADARS ILLUSTRATED WITH THE FMCW SIMULATOR

The frequency-modulated continuous-wave radar (FMCW) is a short-range measuring radar set capable of determining distance. This increases reliability by providing distance measurement along with speed measurement, which is essential when there is more than one source of reflection arriving at the radar antenna. This kind of radar is often used as "radar altimeter" to measure the exact height during the landing procedure of aircraft. It is also used as early-warning radar, wave radar, and proximity sensors. Doppler shift is not always required for detection when FM is used.

In this system the transmitted signal of a known stable frequency continuous wave varies up and down in frequency over a fixed period of time by a modulating signal. Frequency difference between the receive signal and the transmit signal increases with delay, and hence with distance. This smears out, or blurs, the Doppler signal. Echoes from a target are then mixed with the transmitted signal to produce a beat signal which will give the distance of the target after demodulation.

Further Reading:

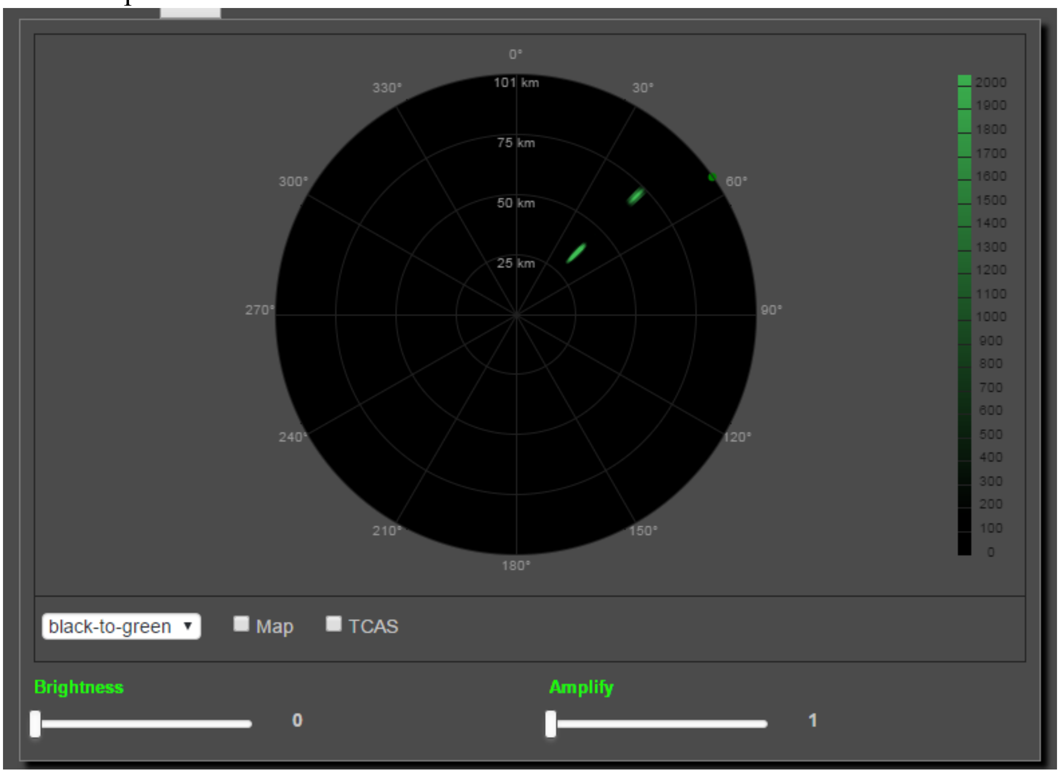
- A presentation on FMCW radars by the University of Sydney

- The chapter on FMCW radars on www.RadarTutorial.eu

6.1 Revisiting the example of two overlapping aircrafts

Let us start with an examination of the case with the two overlapping aircrafts, measured with the FMCW radar.

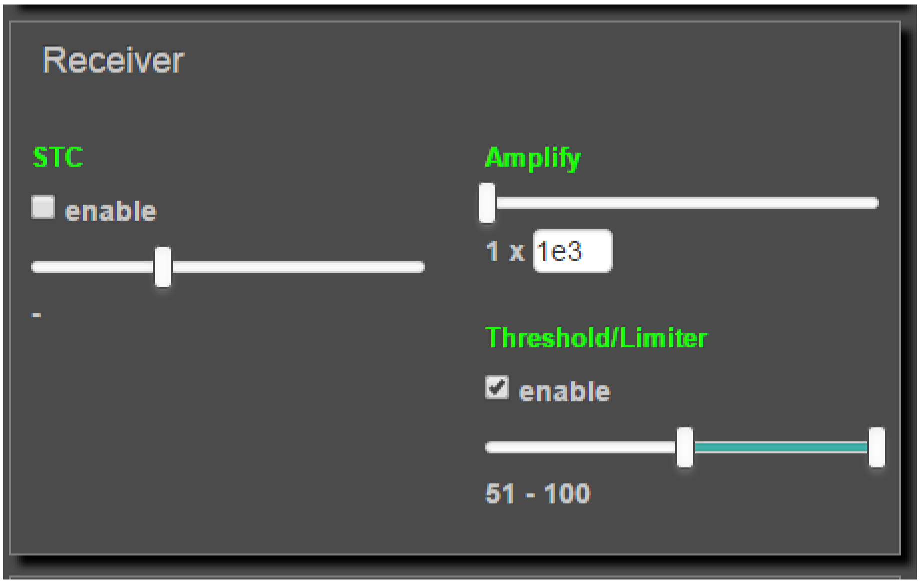
And now please look a



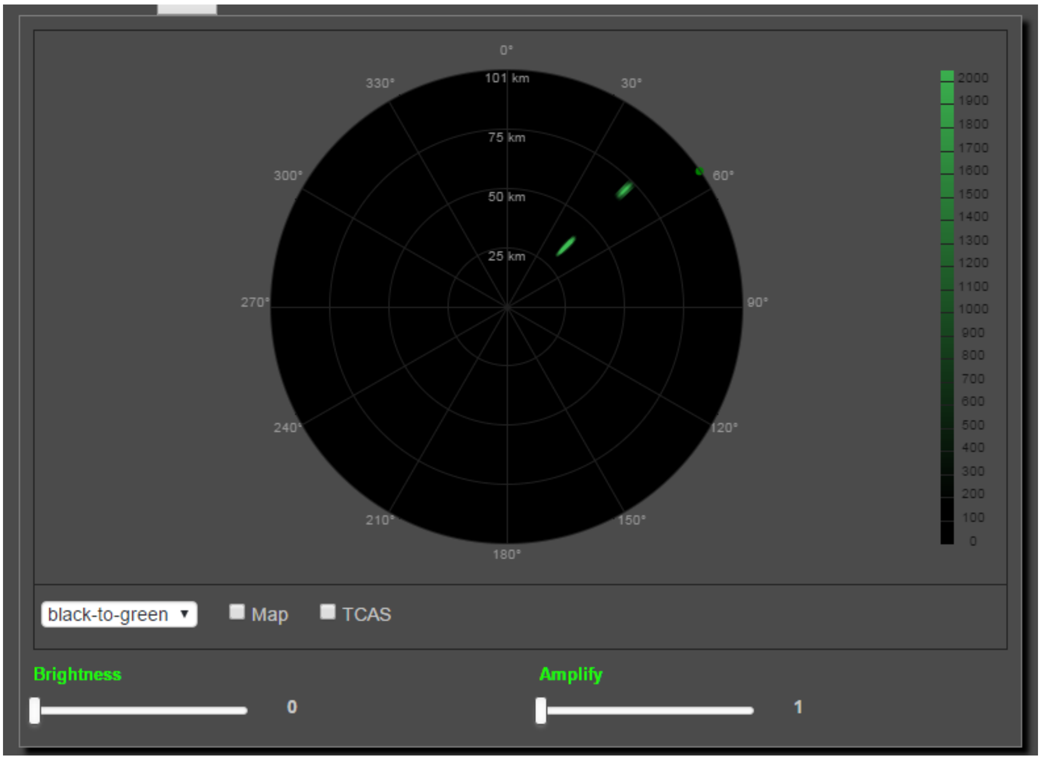
6.2 Impact of Doppler shift on FMCW radar

The PPP settings should be as follows:

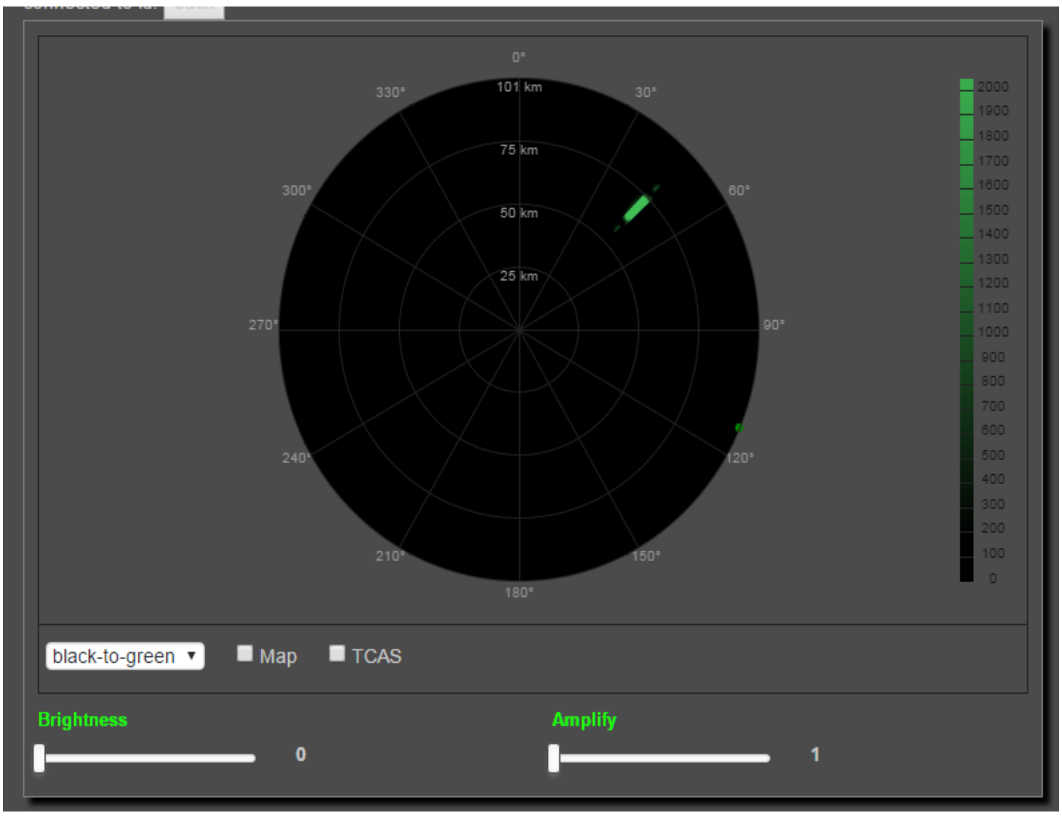
The CWP setting should be as follows:



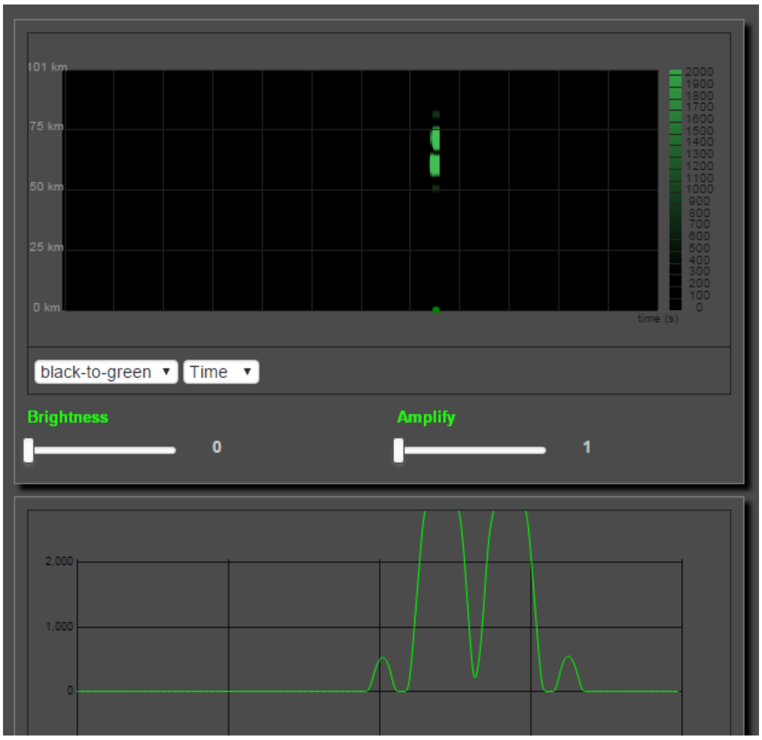
Look at the results in the PPI.



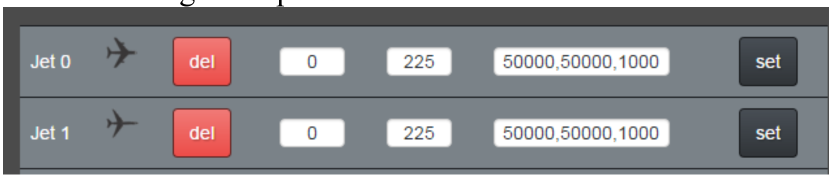
Now let’s decrease the speed for first aircraft to 250 m/s.
On the PPI, the marks appear to be one line, but on the b-scope we can see it as separate objects

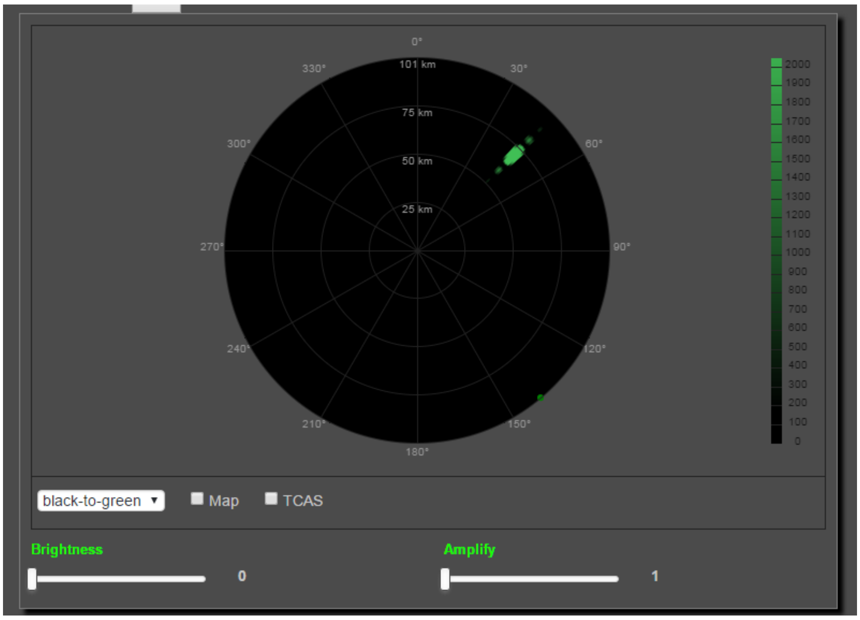


.



Now we change the speed of both aircrafts to zero and can see only one position on display





7 EXAMPLES AND CHARACTERISTICS OF SYNTHETIC APERTURE RADARS ILLUSTRATED WITH THE SAR SIMULATOR

The Synthetic aperture radar (SAR) is a form of radar which is used to create images of objects, such as landscapes – these images can be either two or three dimensional representations of the object. SAR uses the motion of the radar antenna over a targeted region to provide finer spatial resolution than is possible with conventional beam-scanning radars. SAR is typically mounted on a moving platform such as an aircraft or spacecraft, and has its origins in an advanced form of side-looking airborne radar (SLAR). The distance the SAR device travels over a target in the time taken for the radar pulses to return to the antenna creates the large "synthetic" antenna aperture (the "size" of the antenna). As a rule of thumb, the larger the aperture is, the higher the image resolution will be, regardless of whether the aperture is physical (a large antenna) or 'synthetic' (a moving antenna) – this allows SAR to create high resolution images with comparatively small physical antennas.

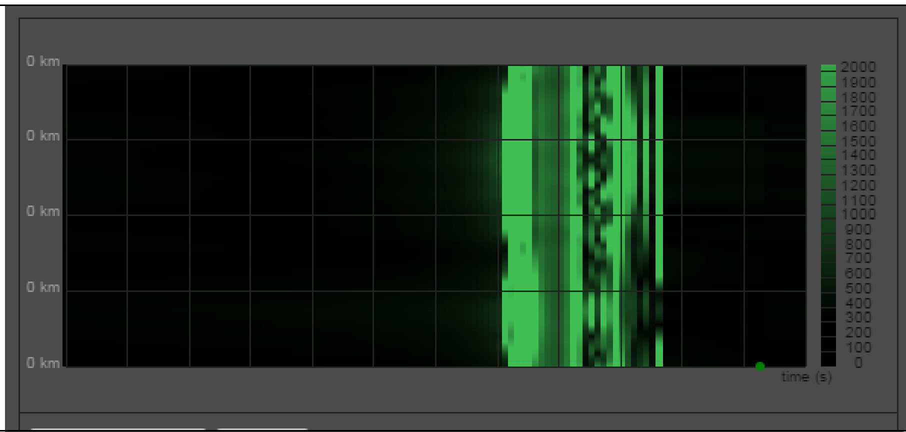
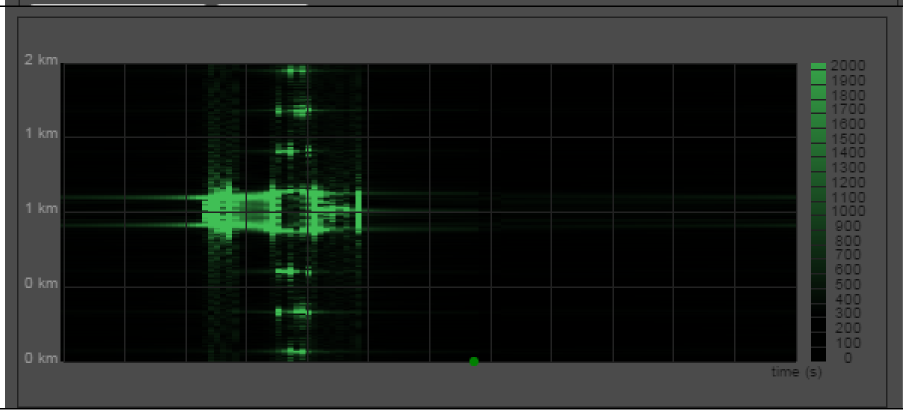
To create a SAR image, successive pulses of radio waves are transmitted to "illuminate" a target scene, and the echo of each pulse is received and recorded. The pulses are transmitted and the echoes received using a single beam-forming antenna, with wavelengths of a meter down to several millimeters. As the SAR device on board the aircraft or spacecraft moves, the antenna location relative to the target changes with time. Signal processing of the successive recorded radar echoes allows the combining of the recordings from these multiple antenna positions – this process forms the 'synthetic antenna aperture', and allows the creation of higher resolution images than would otherwise be possible with a given physical antenna.

In the SkyRadar SAR Simulator, the radar moves along a linear axis to scan the object.

For further reading, please refer to the chapter on SAR/iSAR in the RadarTutorial.eu.

7.1 Creating a high resolution SAR-image

The rule of thumb in the introduction stated that the larger the aperture is, the higher the image resolution will be. To be more precise, it also depends on the number of measurement points (or positions from where you shoot a radar image). Try out yourself in the next exercise.

Not focused image with only 50 *positions* of antenna	
Focused with 300 *positions*	

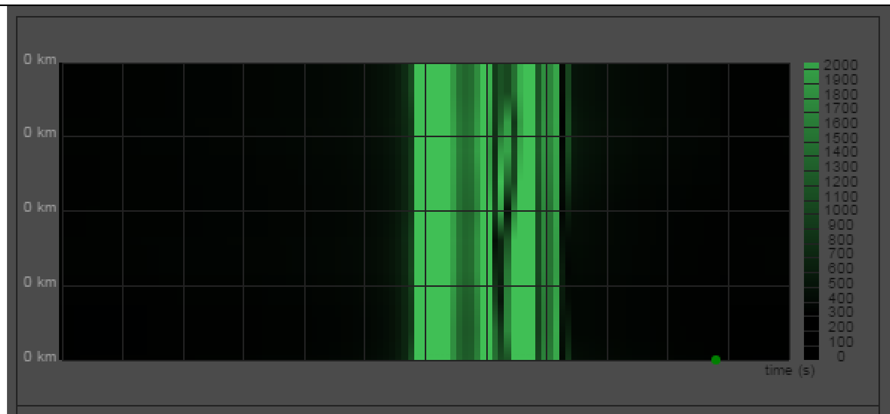
8 EXAMPLES AND CHARACTERISTICS OF INVERSE SYNTHETIC APERTURE RADARS ILLUSTRATED WITH THE iSAR SIMULATOR

Inverse synthetic aperture radar (iSAR) is a radar technique using Radar imaging to generate a two-dimensional high resolution image of a target. It is analogous to conventional SAR, except that iSAR technology utilizes the movement of the target rather than the emitter to create the synthetic aperture. ISAR radars have a significant role aboard maritime patrol aircraft to provide them with radar image of sufficient quality to allow it to be used for target recognition purposes. In situations where other radars display only a single unidentifiable bright moving pixel, the ISAR image is often adequate to discriminate between various missiles, military aircraft, and civilian aircraft.

In the SkyRadar iSAR Simulator, the scanned object moves along a linear axis through the radar aperture.

For further reading, please refer to the chapter on SAR/iSAR in the RadarTutorial.eu.

8.1 Creating a high resolution iSAR-image

The image is the same as in the SAR case, but aircraft moved and we remember and stored signals from different positions N=10 -> 20 positions	
We increase now the accuracy. N=150 -> 300 positions