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HIGH-EFFICIENCY MILLIMETER-WAVE COHERENT RADAR FOR AIRPORT SURFACE MOVEMENT MONITORING AND CONTROL

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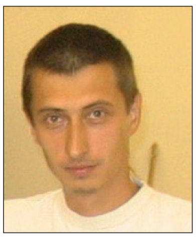

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Abstract. The paper outlines the operation principles, technical characteristics and the field test results of the innovative Ka-band radar for airport surface monitoring. Advantages and disadvantages of operation in the Ka-band with respect to a shorter one, i.e. The W-band, are discussed. It is shown that in the Ka-band the coherent operation mode can be realized. This mode enables one not only to essentially reduce the radiation power to the level provided by the available semiconductor devices, but also to perform moving target detection on interference created by reflections from surface objects and rain as well as to perform automatic classification of targets according to their radial velocity of movement. Main performance specifications, principle of operation, and design of the innovative antenna developed for the radar are described in detail. The results of the field tests confirm the predicted radar operation characteristics. The radars of the proposed type can be used as radar-sensors for systems of airport surface monitoring.

Keywords: Airport surface monitoring, Coherent radar, Primary radar, Ka-band, A-SMGCS, DSP.

1. Introduction

Engineering methods play an important role in the safety of aviation transport, including both aviation security and flight safety. The major areas in which progress is obviously related to safety are, first of all, new lighting systems, novel precision approach and landing systems associated with satellite-based navigation, visual docking guidance systems for aircraft parking, automated meteorological systems, and, of course, surface movement radar (SMR). In essence, safety is the elimination of risk or its reduction to a minimum. Risk grows steadily with the intensity of flights. Moreover, intensive flights demand round-the-clock operation from the airport.

Adverse weather and work at night can be threatening conditions. That is why the advanced surface movement guidance and control systems (A-SMGCS) are really necessary for accurate and reliable determination of aircraft position. The A-SMGCS is also required for monitoring (detection, tracking and identification) of other objects in the airport area. Research and development of new generation systems have been underway to introduce new capabilities, such as an airborne display unit to visualise aircraft position on the airfield, places of other planes and vehicles, and even the path to be taken and, perhaps, air traffic control instructions. Accurate and reliable sensors are necessary in order to provide such detailed information. It is reasonable to note that A-SMGCS data are required for both air traffic controllers and crew members.

Such systems should be fully tested, commercially available and ready to be used in the near future, making up an important part of the overall Safety Management System (SMS) for airports (Advanced…2004). According to the definition of ICAO, the SMS is "a systematic approach to managing safety" that should act everywhere on the airfield, including runways, taxiways and aprons. This is especially important to provide security against, e.g., runway incursions or to reduce any kind of risk in special areas of the airfield. The SMS relies heavily on safety assessments whereby the risk is estimated for every procedure, operation or situation, taking place in the airport zone. This enables the operator to eliminate or reduce the risk of an accident/incident to the lowest possible level. Such an approach has proved to be a very good method towards better safety at airport (Airport… 2009).

The Advanced Surface Movement Guidance and Control System at an airport is a surveillance infrastructure consisting of Non-Cooperative and Cooperative Surveillance.

EUROCONTROL announced the following functional features required from the A-SMGCS at Level 1 (EUROCONTROL… 2003).

Acquisition of traffic information from non co-operative targets,

- Acquisition of traffic information from co-operative targets,
- Acquisition of traffic information from approaching targets,
- Acquisition of other information about traffic,
- Data fusion,
- Acquisition of traffic context,
- Interface to user,
- Service monitoring.

The acquisition of traffic information from non-co-operative targets normally calls for one or more SMR or some other active sensors, such as Microwave Sensors or Optical Sensors.

The traffic information from Co-operative targets can be acquired in a variety of ways, but today the most common is the usage of a Multilateration technique employing an airborne Mode-S transponder. The position of the target (aircraft) is calculated according to the time difference between spontaneous emissions received from the target. The identification (aircraft identification or call sign) is accomplished by the active interrogation of the transponder. If a vehicle is not originally equipped with a standard detector, such as a Mode-S Transponder, it should be provided with Mode-S transmitters or such special instruments that can be detected by the Multilateration system carrying a number of receivers. An approach to optimal arrangement of these receivers can be found in (Konchenko, Yanovsky 2009).

The primary and the secondary surveillance radar devices are current standard means of moving aircraft detection. Wide Area Multilateration is also used.

Finally all pieces of the survey and any other material are collected in the data fusion system, ensuring that the user gets all the information about targets in the airfield.

This paper presents a prototype of the SMR device developed as a part of the A-SMGCS. Today's millimeter wave radar technology is efficient enough to be in common current use, including aviation (Yanovsky 2008). It is no wonder that the SMR developed in the Institute of Radio Physics and Electronics of the National Academy of Sciences of Ukraine operates at millimeter wavelengths.

2. Subject and methodology

A Ka-band radar sensor is suggested as a building block of the primary multisensory network entering the A-SMGCS. A sensor modification completed with an off-line indication system can do airfield surveillance at small aerodromes and deal with work territory control problems too. A general view of the radar sensor is shown in Fig. 1.

Fig. 1. A general view of the radar sensor

The main feature distinguishing this radar unit from analogous devices (Ferri *et al.* 2001; Galati *et al.* 2004) is a original combination of solid-state receiver-transmitter coherent operation with a high enough pulse power in Ka-band to gain the following:

- automatic identification of moving objects upon the Doppler shift of the radar signal frequency: the target selection is an ICAO requirement imposed upon the A-SMGCS,
- coherent accumulation of the received radar signals makes it possible to substantially (here more than ten times) reduce the sounding waveform radiation power and accomplish a totally semiconductor transceiver.

According to the analysis performed (the results are briefly summarized in (EUROCONTROL…2003), it is in the Ka-band that a new-type radar sensor can be developed without a traditional magnetron. Some other developers still use it as a sounding waveform source. The merits of the Ka band usage are:

- antenna aperture size is 3 to 4 times smaller (compared to the centimeter-wave X band) and, hence, the antenna drive system is of lower cost,
- substantially less rainfall attenuation compared to the millimeter-wave W band (3-4 dB/km in

10-16 mm/h precipitation for the Ka band and 6-9 dB/km for the W band) and a 2–3 times lower specific radar cross-section of precipitation,
- availability (against the W band) of Ka-band receivers (noise Figure below 5 dB) and Ka-band pulse amplifiers (output power up to 50 W).

According to our numerical results, it is in the Ka-band that the basic components are developed to the point where a entirely semiconductor radar unit can be completed, having a 5 km range available in dry weather and 2 km in 16 mm/h rain, the target being of a 1 m^2 radar cross-section, which corresponds to a person or a big animal.

The radar sensor has already been developed, constructed and tested. For its performance, see the Table 1.

The functional diagram is a typical one for coherent-pulse radar with absolute coherence, which means that all the frequencies-carrier and heterodyne, intermediate, repetition and sampling in the analog-digital converter-are provided by the unique quartz-locked oscillator.

The transceiver antenna operates upon surface to spatial wave conversion when the surface wave of the dielectric waveguide is interacting with the conducting periodic structure. This antenna has a plane aperture of a size determined by the radiation pattern widths in the horizontal and vertical planes. From structural considerations, the antenna thickness is rather small—a few centimeters only. A general arrangement of the antenna is seen in Fig. 2.

The transceiver from Saturn in Kiev involves:
- a reference frequency synthesizer for all the necessary frequencies (carrier, heterodyne frequency, repetition frequency, sampling frequency, etc.),
- a high-power Ka-band pulse amplifier to produce sounding pulses,
- a high-sensitivity receiver supplied with a Ka-band input amplifier and a converter,

Table 1. Major characteristics of the radar sensor

Carrier frequency	36 GHz
Repetition frequency	20 kHz
Pulse duration	100 ns
Pulse power	20 W
Receiver noise figure	< 5 dB
Intermediate frequency	9 GHz
Antenna pattern width: in azimuth in elevation	 0.25^0 3^{0}
Rotation velocity of the antenna system	0.25 rev/s
Power consumption	<1 kW
Mass	< 150 kg
Antenna height	5-10 m

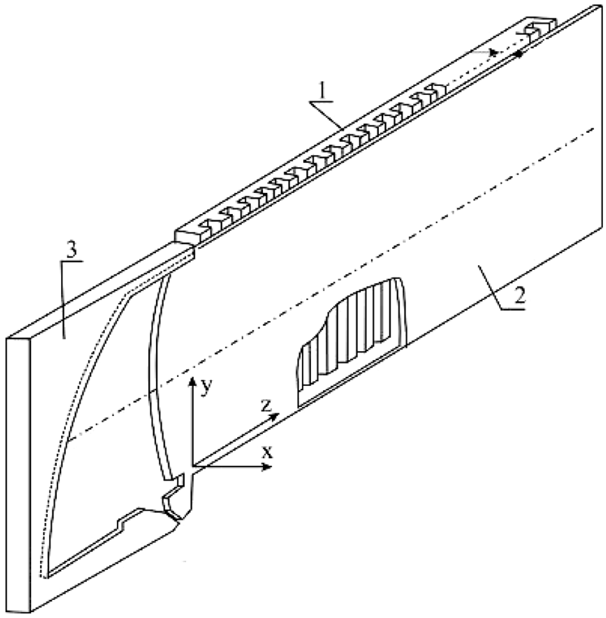

Fig. 2. The transceiver antenna: 1 – diffraction grating, 2 – planar dielectric waveguide, and 3 – parabolic horn feed

- an intermediate-frequency amplifier,
- a two-channel synchronous output detector.

Received signal processing is featured by the synchronous analogous detection of the signal with two quadrate components. These are subjected to analog-digital conversion at a 40 Mhz tact frequency and subsequent digital processing which starts with packet forming. Each packet consists of 64 readings and corresponds to the time it takes for the antenna to illuminate a point target during its circular scanning. After the Fourier transform, the amplitude of each packet harmonic is checked against a chosen detection threshold. If the threshold is overshot, a decision is made that a target exists, its location is evident from the packet delay and the antenna rotation angle, and its radial velocity corresponds to the Fourier spectrum harmonic position. All detected targets are divided into four velocity groups based on the amplitude summation figures of the Fourier harmonics corresponding to the detected targets and falling into the four frequency intervals not overlapping one another. The frequency bounds are preset by the operator, which allows, in particular, diminishing of the effect of speedy target masking by rain clutter. In the further indication process, reflections from different velocity group targets are marked by different colors.

The output of the digitally processed information about all reflecting objects in the radar surveillance area is coded and radio-channeled through the remote access device to the information imaging unit. The same radio channel is used to take control of the transceiver and the digital processing system. The transceiver and the digital processing system share a sealed metal container mounted at the back of the antenna.

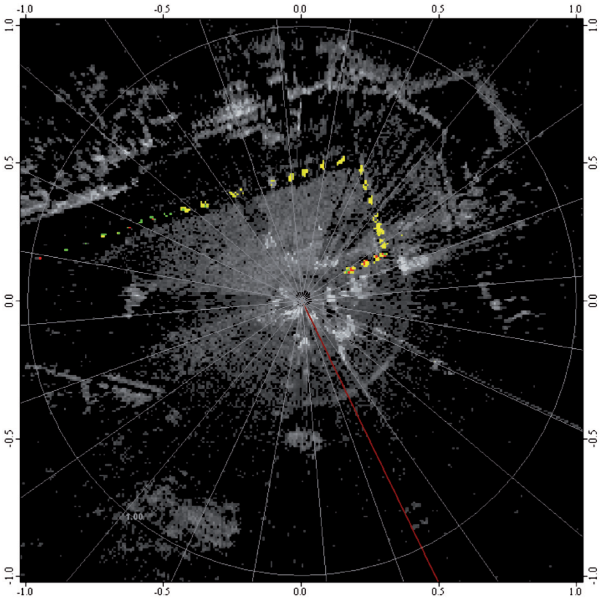

Fig. 3. The radar image of part of the airport area with an Antonov-140 plane moving along the taxiway and the runway

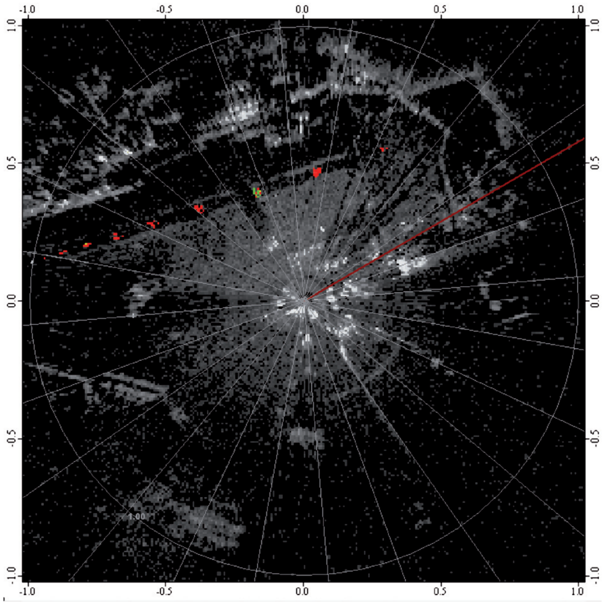

Fig. 4. The radar image of part of the airport area with an Antonov-12 plane landing

3. Experimental results

From 2003 to 2010 the suggested radar sensor was prototyped, tuned-up and tested sequentially in several variants, mostly by the availability of new, more advanced microwave/millimeter-wave devices and digital facilities. Preliminary tests consisted of observation and analysis of the reflections from corner reflectors, vehicles, and humans in their motion across a chosen area free from objects that could produce a strong clutter. The tests showed that the design characteristics agree with the measurements

The principal tests (Yevdokimov *et al.* 2003) were performed in the airfield of the Kharkov airplane plant. The observation objects were automobiles and people en route, snow ploughs and vehicles working on the runways and, of course, aircraft taking-off, landing and maneuvering. The experimental results are illustrated in Figs 3 and 4. In the aircraft reflection process, any change in the radar mark color is readily displayed, associated with a change in the target velocity radial component with respect to the radar mounted at the side of the runway.

Currently, possibilities are being considered of a faster renewal of information by changing from circular to sector surveillance. For this purpose, a sensor will be employed with a pair antenna possessing higher rotation speed.

The employment of a WI-FI system for the data transmission interface makes it possible to readily integrate the sensors into a single information network using standard methods of data transmission and routing in local networks. The synchronisation of several sensors and data integration from several radar devices into a single network picture will be provided by a data fusion unit that is under development. The launch of the fusion unit will accelerate the information renewal and remove radio shadow zones.

Also, there could be a possibility to combine the software used with the Multilateration fusion to be incorporated into the A-SMGCS structure.

4. Conclusion

The prototype development and testing have given good grounds for the assurance that ecologically friendly, high-performance Ka-band radar can be realised with parameters expected from A-SMGCS sensors. In Ukraine, the necessary basic components are available, and the productive capacities meet the requirements.

An important feature of the developed of SMR is its operation as a sensor of the near-range primary radar network to cover the whole airport surface. The merits of the proposed SMR are enhanced by the benefits of the high quality-price ratio and the reasonable mass and size of the system.

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DIDELIO EFEKTYVUMO MILIMETRINIO DIAPAZONO KOHERENTINIS RADIOLOKATORIUS MONITORINGUI IR ANTŽEMINIO JUDĖJIMO VALDYMUI ORO UOSTUOSE

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Santrauka. Straipsnyje aprašyti naujo koherentinio radaro darbo principai, techninės charakteristikos ir lauko bandymų skrydžių lauko apžvalgai 8 mm diapazonu rezultatai, palygintos 8 mm sistemų ir jų trumpabangių analogų charakteristikos. Parodyta, kaip galima taikyti koherentinį režimą. Toks darbo režimas leidžia ne tik sumažinti išspinduliuojamą radaro energiją iki šiuolaikine puslaidininkių įranga sukuriamo lygio. Koherentinis režimas leidžia atlikti judančių objektų doplerinę selekciją stiprių atspindžių nuo stacionarių objektų ir kritulių sąlygomis. Tai leidžia klasifikuoti tikslus pagal greičio požymius. Aprašomi pagrindiniai parametrai, veikimo principai, šiam radarui sukurtos antenos sandara. Lauko bandymų rezultatai rodo, kad sistema sutampa su pasirinktais parametrais. Pasiūlytas radaras gali būti naudojamas skrydžių lauko apžvalgos sistemose.

Reikšminiai žodžiai: pirminis radaras, koherentinis radaras, skrydžio lauko apžvalga, MM bangos, A-SMGCS, ЦОС.