Passive Radars as Sources of Information for Air Defence Systems

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SUMMARY

Passive radars have some advantages as sources of information for air defence systems as compared with active radars, emissions of which can be easily detected and then countermeasure means may be used. The main advantage of passive radars is a covert operation based on signals of opportunity, especially using signals emitted by commercial broadcasting stations. Many features of passive radars like resolution and estimation of air object coordinates depend on captured signals. Examples of range resolutions achieved using UHF radio broadcasting and TV broadcasting signals are discussed basing on references enclosed. The uncertainty in range is explained and its influence on range estimation accuracy is indicated. The dependency of air coverage volume on the number and localization of emitters has been explained. A comparison of fundamental parameters of active radars (used nowadays widely by air defence systems as sources of information about air situation) and parameters achieved by passive coherent location (PCL) radars is presented. The important disadvantage of passive radars is their strong dependence on quality of broadcasting signals. They can be switched off during the critical situation or war actions . Another problem can occur during the change of the battle theater, when in the area of interest the density of broadcasting stations is very low.

The result of the discussion on features of both active and passive radars is concluded in that, that passive radars do not match some of temporary requirements of air defence systems and cannot now replace active radars but can be used as a supporting sources of information during the peace time and critical situations. Passive radars can improve a radar coverage for small RCS objects ("stealth") as well as low altitude coverage what supports early warning function.

1 INTRODUCTION

Land based and airborne radars are basic information sources about air situation for defence systems and in spite of growing role of satellite radars still play the main role in delivery of required data to defence systems. The importance of radar data for defence systems is confirmed by examples of military actions during contemporary wars (e.g. Iraq), when the first mission was performed against air defence systems radars. So called active radars emit transmitting signals which are captured by the ELINT systems or ESM receivers installed on airborne platforms. However, the received radar signals allow estimation of the radar site and its attack by planes or ARMs. The passive radars, which do not emit transmitting signal, are preferred for providing radar coverage in such battle circumstances.

The concept of passive radars using signals of opportunity was proved during the Second World War [1] as a very useful tool in electronic reconnaissance of air situation. In spite of many decades of continuous development of methods implemented in passive radars, there exist a large area of problems which are to be explored. It should be noticed that intensive research on passive radars are still performed by many universities and research institutions which result in large number of publications [2, 3,4]. Many of them are very enthusiastic about features of passive radars (especially PCL) and their competitiveness against active radars exploiting its own dedicated transmitters. This sometimes may lead to the situation when military users are close to the idea of possible replacement of active radars by passive radars, which is, unfortunately, not so very likely. So, it is very important for military users to deeply understand differences in features of passive location radars and active radars for proper management of their output data in real environment.

2. RADAR COVERAGE PROBLEM

Radar data as an output information from surveillance radars are delivered to air defense systems, where after data fusion represents Recognized Air Picture (RAP). This picture (RAP) is basic information for taking decision process during military missions. So, the input radar data should be the best quality in the sense of statistically described radar coverage because any instability of it could cause loses during military missions.

Users of radar information on air space situation require a radar coverage of defined air volume with statistically described detection features for some class of air objects. These features should be stable in time and degradable in predicted manner versus changing jamming situation. A continued surveillance of air volume, especially for early warning, requires a radar coverage without blind zones at determined altitude. This problem is well known in the bi-static configuration of passive radars [5], where such zone exists between emitter and radar receiver and in practice, may be solved by multi-static configuration. Elimination of such blind zones is a very difficult task and it is assumed that is not possible to fully solve it in configuration met in a real situation.

One of directions of PCL radar development is usage of transmitting signals of surveillance radars both military and Air Traffic Control (ATC). The usage of ATC radar signals is particularly attractive due to the fact that ATC radars network exist in any country. Methods and basic formulas for configuration using active surveillance radar and PCL radar are given in [6] and show that some increase of detection in defined azimuth sectors can be achieved.

Some of PCL radars use broadcasting signals or public TV signals as signals of opportunity and the question remains how many emitters are needed and what their configuration should be for assuring continuous coverage for surveillance mode around the PCL radar .

The answer to this question may be offered by simulation of a PCL radar coverage (as an theoretical example) using at least ten FM broadcast stations which results in a 50 km range [7] . In real environment, such density of radio broadcast stations is very seldom and the required geometrical configuration is difficult to achieve. The result of this modeling indicates however that an achievement of continuous coverage for the surveillance mode with a help of PCL radar is in practice extremely difficult, especially for an area where broadcasting emitters are installed in the certain configuration. Another conclusion is, that PCL radar is rather dedicated to improve radar coverage in the area of interest taking into account the existing configuration of broadcasting stations.

Additional problem of stability of PCL radar coverage (defined as a stable statistical detection features, described in many works) is dependent on a quality of FM broadcast when autocorrelation function of emitted signal is changing with FM broadcast (music, speech, pause etc.). This effect leads to a situation when the detection features of PCL radar will fluctuate in time and for defined moments are not predictable.

3. GEOMETRY DEPENDENT SIGNAL PROPERTIES

PCL radars are operating in bi- or multi-static configuration, where transmitters and receivers are separated in distance which modifies range estimation equation, as it is explained in many published works. The bi-static range represents an ellipsoid in 3D coordinates, because the range estimation during measurement time is dependent on an unknown target elevation angle, which results in so called range uncertainty [5]. In the work [5], it is given an example of a bi-static radar with non-cooperative transmitter operating as a 2D radar with rotating antenna, having narrow azimuth and wide elevation beamwidth as typical for ATC radars. Because there is no analytical expression for a range uncertainty it was analyzed for several flight paths in the transmit-receive plane. The result of analysis has shown that level of range uncertainty is dependent on distance from baseline and transmitter-target angle and it achieves level, which should be taken into account as a limitation of range estimation accuracy. The above described problem of range uncertainty is an area of possible further research to find methods of limitation or compensation of this effect in PCL systems, when 2D or 3D surveillance radars are the sources of illuminating signals.

4. LIMITATION OF RANGE RESOLUTION BY SIGNAL PROPERTIES

One of the most important requirements for radar data used by the air volume control systems is a range resolution, which limits of range separation of air objects. In contemporary air control systems it is required to assure the level of range resolution of tenths of meters. The width of main peak of ambiguity function of transmitting signal defines range resolution in bi-static range coordinates. The features of basic types of signals of opportunity, used in passive radar systems such as illuminating signals, were summarized in work [8] and in Table 1 and can be used as a base for estimation of signals usefulness. Analog signals of FM radio and TV (including DAB) have potential range resolution of several kilometers, which indicates of its poor usefulness for passive radar systems as source of information for air control systems. The DTV signals have good potential range resolution but low peak range sidelobes, which limits dynamic range of receiving signals. Additionally, high range sidelobes can create false detections and increase the problem of “ghost” detections. Signals of GSM and GPS are too weak to be exploited in passive radar systems for air traffic control with required detection ranges.

Table 1. Signal characteristics of transmitters of opportunity [8]

Transmitter	Typical ERP [kW]	Level [dB/m^2]	Range resolution [km]	Peak sidelobe level	
				Range [dB]	Doppler [dB]
FM radio analog	50		1.8 – 16.5	-12.0 -12.7 [1]	-26.0 - -46.5
Analog TV	100		9.6 [2] – 15.6	-0.2	-9.1
DAB	10		1.5	-11.7	-38.0
DTV	10		0.044	-18.5	-34.6
GPS		-130	0.030		
GSM 900 MHz		-80 [3]	1.8	-19.3	-46.7

5. COMPARISON OF FUNDAMENTAL FEATURES OF ACTIVE AND PASSIVE RADARS

An active radar defined in this paper as a radar with its own transmitter or active antenna array is widely used as source of information in ATC and defense systems, because detection features are defined by statistical parameters given by the producer. The stable and guaranteed, statistically described radar coverage, is fundamental when taking decision processes in defense systems. The higher cost of active radar is accepted when this particular feature is a priority for an air situation control system. Passive radars, especially of PCL class, have detection features dependent on many factors like type of signal, fluctuation of signal dependent of content of broadcast, number of signal emitters, configuration of signal emitters and passive radar (terrain localization). Those factors are not controlled by the producer of PCL radar and who therefore cannot be responsible for final detection features and stability of radar coverage. It is required for each new PCL localization to introduce parameters of selected emitters, so this introduction can be supported by preparation in advance a data base for the region of planned activity. But always an operational staff should check the emitters activities at new radar site and choose the best suitable signals of all received. Some emitter's signals from the data base can be distorted by terrain obstacles. This process, necessary before start of normal operation of any PCL radar requires highly skilled staff and the exploitation itself is more like that used in electronic warfare operation then as a standard radar operation. The main advantage of PCL radar is a covert operation because localization of PCL radar cannot be made by detection of EM signals. Unfortunately, to assure omni-directional radar coverage in the azimuth plain by a PCL radar, a number of transmitters are required in the given configuration, which rarely happens in the real environment. So, PCL radar is rather dedicated to cover some sectors of planned air objects activity than for omni-directional coverage as it is the case in surveillance radars. Some basic features of active and passive radars are listed and compared in Table 2. The comparison should allow better understanding of differences in features from point of view of a user. It should be noted that PCL radars allow to achieve very high rate of data renewal which is difficult to get in standard active radars. High rate of data renewal is a basic parameter for artillery shells tracking or fast maneuvering missiles.

Table 2. Comparison of basic features of active and passive radars

Active Radar	Passive Radar (PCL)
Controlled defined signal generated by its own transmitter or active antenna	Exploitation of signals of opportunity e.g. FM radio, DAB, DTV or civil and military surveillance radars and receivers matched to chosen signal
Transmitting signal detected by ELINT systems or RWR/ESM and ARM receivers	PCL station not detected by ELINT or RWR/ESM and ARM receivers
Detection features depends on intentional jamming	Detection features depends on signals of transmitter of opportunity and its localization bat also on intentional jamming in some EW activity
Defined statistically radar coverage for assumed clutter and jamming for certain class of air platforms	Radar coverage dependent of many factors: transmitters of opportunity configuration, type of signal, PCL localization, transmitting signal presence.
Detection improvement by frequency diversity	Detection improvement by frequency and space diversity, enhancement of RCS for some directions
Large volume of equipment, large energy consumption, high cost of transmitter	Low volume of receiving part, simple antenna architecture, possibility of COST equipment implementation
Small and predictable estimation errors of coordinates	Estimation errors in range dependent on kind of signal of opportunity and other factors
Fixed SW for several modes of operation of radar, independent on radar site	Require introducing parameters into SW after each change of radar site or configuration of transmitters
Radar staff after training by producer	High-skilled staff required
Theoretical constant detection range of small RCS targets suitable for early warning (for high power surveillance radars)	Extended detection range of small RCS targets, dependant on angle of observation

Active Radar	Passive Radar (PCL)
Data rate of 2-10 s	High data rate (1s)
High range resolution with coded transmitted signal	Range resolution dependent of chosen signal of opportunity
High accuracy of elevation angle estimation by 3D radars (≤ 0,3° rms)	Low potential accuracy of angle estimation (≥ 2-5° rms)

Nowadays 3D radar data, which describes target position in three coordinate's space, are obligatory required as an input data to air defence systems. For effective tracking of target, a high accuracy of estimation in three coordinates is required. The required accuracy in range can be achieved by proper choice of illuminating signal (see Table 2). Estimation error in azimuth plane is dependent on antenna aperture and estimation method, so the required level of accuracy can be matched by PCL radar design. But more difficult is to meet required level of error in elevation, because some attempts has shown possibility of estimation by passive radar with an error at the level of several degrees, which is far behind acceptable level. It means, that to meet military requirement of elevation estimation error, further research of methods and concepts of passive radars is needed.

6. CONCLUSIONS.

As it was above indicated, passive radar is not a remedy for situation when a radar coverage of active radar can be decreased or eliminated by passive (jamming) or active countermeasures by destroying radar. Still, active radars are fundamental means for providing air surveillance but PCL radars can enhance features of radar coverage in some limited sector or improve its statistical detection parameters. Additional question is, if defined emitters used in PCL radar system will be at disposal when any military action will start. This problem leads to a conclusion that passive radars are rather dedicated to provide covert air volume reconnaissance during peace time, which is also very valuable, because it is not recognized by a potential enemy and it can warn of possible hostile action.

It should be noted that methods and concepts of passive radars are still in the development phase due to continuous development of signal of opportunity sources both commercial and military. Wide implementation of digital TV and broadcasting in many countries gave an impulse to new research and experimental trials. But some fundamental features of passive radars indicated in Table 2 are unchanged because these features are coming from basic concept of passive radar.

Development of radar technology and passive radar methods can improve some parameters which will influence wider practical implementation of passive radars in defence systems.

Actual state of art of passive radar technology rather places them as a supporting very useful tool for gathering 2D radar data, which can enhance parameters of radar coverage. Passive radars cannot replace active radars as source of information for defence systems but they can enhance the detection of air objects after data fusion, improving, for example, detection of low flying objects or detection of low RCS objects.

7. REFERENCES

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