MULTISTATIC PASSIVE RADAR FOR IONOSPHERIC SOUNDING

Svetoslav Zabunov, Garo Mardirossian

Space Research and Technology Institute – Bulgarian Academy of Sciences
e-mails: svetoslavzabunov@gmail.com, garo.mardirossian@gmail.com

Keywords: *Multistatic passive radar, Passive radar for ionospheric sounding*

Abstract: *The subject of passive radars has been advancing lately due to the progress in supercomputing hardware and its broader availability, mobility and lower power consumption. Passive radars have implementation in tasks such as detection, tracking and identification of radio-reflecting targets, either flying, sailing or ground-based. Passive radars are also productive in science, specifically in remote sensing of the ionosphere from the Earth's surface. Their major advantage over active radar systems is the absence of a maintained radio transmitter and of all related drawbacks such as licensing, disclosure of location, high power consumption, etc.*

Multistatic passive radars are essentially the state-of-the-art in this technology. They deliver unmatched quality of detection and imaging due to the utilization of multiple transmitters and/or receivers.

The present paper focuses on a novel multistatic passive radar now under development at the Space Research and Technology Institute – Bulgarian Academy of Sciences. The radar makes use of commercial broadcasting transmitters located in Bulgaria and some of the neighbouring countries. The frequency range of the radio waves is 87.5 to 108 MHz and the modulation is FM.

Our novel system has protection from the Bulgarian Patent Office by Utility Model #3928 / 29.Oct.2020.

МУЛТИСТАТИЧЕН ПАСИВЕН РАДАР ЗА ЙОНОСФЕРНИ ИЗСЛЕДВАНИЯ

Светослав Забунов, Гаро Мардиросян

Институт за космически изследвания и технологии – Българска академия на науките
e-mails: svetoslavzabunov@gmail.com, garo.mardirossian@gmail.com

Ключови думи: *Мултистатичен пасивен радар, Пасивен радар за йоносферни изследвания.*

Резюме: *Темата за пасивните радари напредва в последно време поради прогреса в суперкомпютърния хардуер и неговата по широка достъпност, мобилност и по-ниска консумация на енергия. Пасивните радари имат приложение в задачи като откриване, следене и идентификация на радио-отражателни цели, както летящи така и плавателни и наземни. Пасивните радари са полезни в науката, конкретно в дистанционните изследвания на йоносферата от повърхността на Земята. Основното им предимство пред активните радарни системи е липсата на поддръжка на радиопредаватели и всички съпровождащи ги недостатъци като лицензиране, разкриване на местонахождението, висока консумация на електроенергия и др.*

Мултистатичните пасивни радари са в действителност върховото ниво на техниката в тази област. Те предлагат качество без конкуренция при откриването на цели и създаването на изображения на наблюдаваните обекти. Това се постига чрез използване на множество предаватели и/или приемници.

Настоящата статия се фокусира върху иновативен мултистатичен пасивен радар който в момента е в процес на разработка в Института за космически изследвания и технологии – Българка академия на науките. Радарът използва комерсиални радиопредаватели за радио разпръскване, намиращи се в България и някои от съседните държави. Честотният обхват на радио вълните е от 87.5 до 108 MHz, а модулацията е честотна.

Нашата иновативна система разполага със защита от Патентно ведомство на Република България чрез полезен модел №3928 от 29.10.2020.

Introduction

The passive radar systems are employed in detection, identification and tracking of objects, either flying, sailing or traveling on the ground. The passive radar does not rely on purposefully created and maintained radio transmitters, but instead uses transmitters of opportunity also called non-cooperative transmitters. When the radio waves emitted by the radio transmitters of opportunity bounce back from the target, the reflected waves are received by the radio receiver of the passive radar. Direct waves from the transmitters are also received. After appropriate computations the target's parameters are found such as speed, direction of movement, etc. (see Fig. 1).

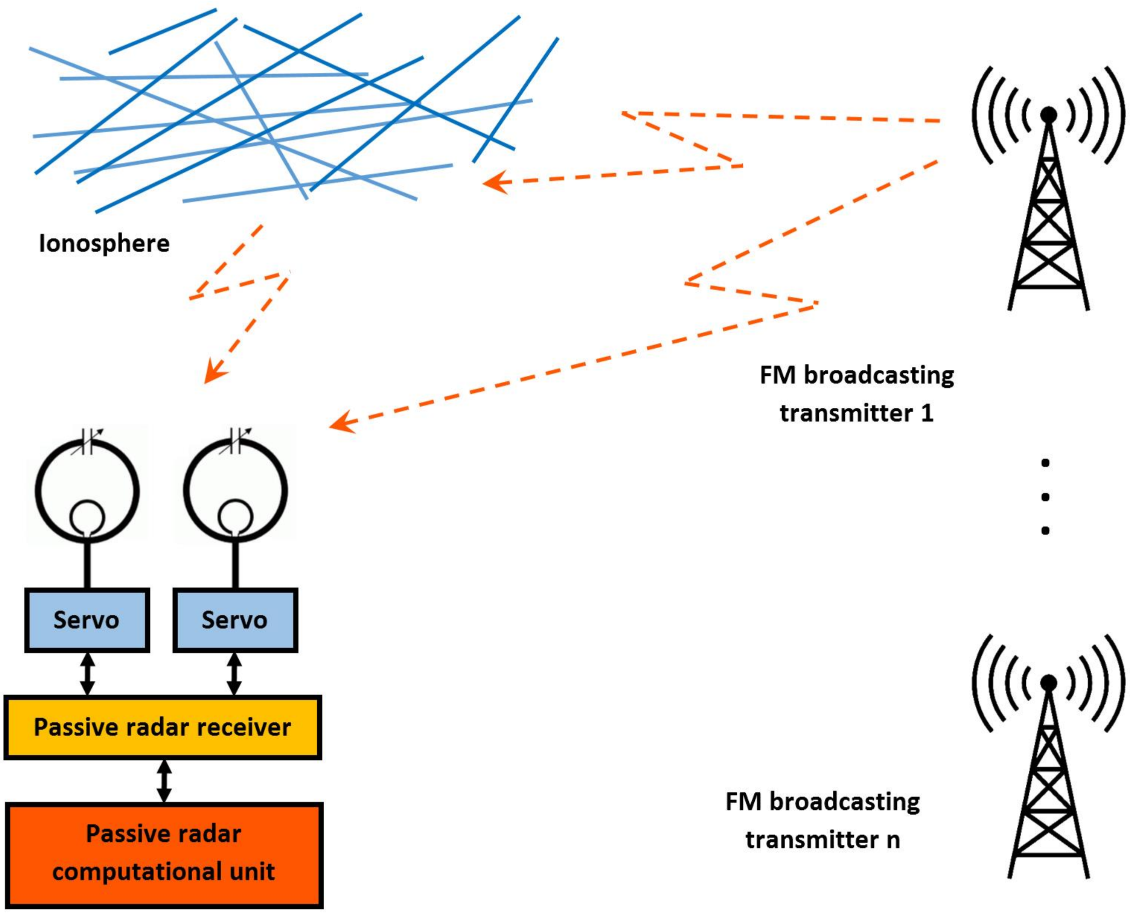

Fig. 1. The passive radar is used for ionospheric sounding. Transmitters of opportunity emit radio waves that bounce back from the ionosphere and are received by the radar equipment.

The passive radar can be used to observe small and large objects and it is suitable for observation of the ionosphere which is a large object with reflective properties in the high frequency (HF) and very high frequency (VHF) radio bands. Currently in Bulgaria there are no operational passive radars for ionospheric observations. The instrument that is sounding the ionosphere and is operational is the ionosonde station at the Geodesic Observatory "PLANA" belonging to the National Institute of Geophysics, Geodesy and Geography – Bulgarian Academy of Sciences. Due to the requirements for the transmitters to have considerable power, specific modulation and be working in the mentioned radio bands, only the frequency modulated (FM) commercial broadcasting transmitters are applicable as transmitters of opportunity for ionospheric observations.

Passive radars are of two major types: bistatic or multistatic. The bistatic variant employs one receiver and one transmitter, while multistatic passive radars use several non-cooperative transmitters and/or several receivers, all of which are located at considerable distances from each other. Multistatic passive radars offer the ability to create 3D image of the observed volume – a beneficial feature for ionosphere remote sensing.

Recently, passive radar developments have grown in number due to their alleged potential to detect stealth aircraft. This is possible only when employing non-cooperative transmitters emitting radio waves in the VHF and lower radio bands where the wavelength is long enough to counteract the stealth countermeasures of the aircraft.

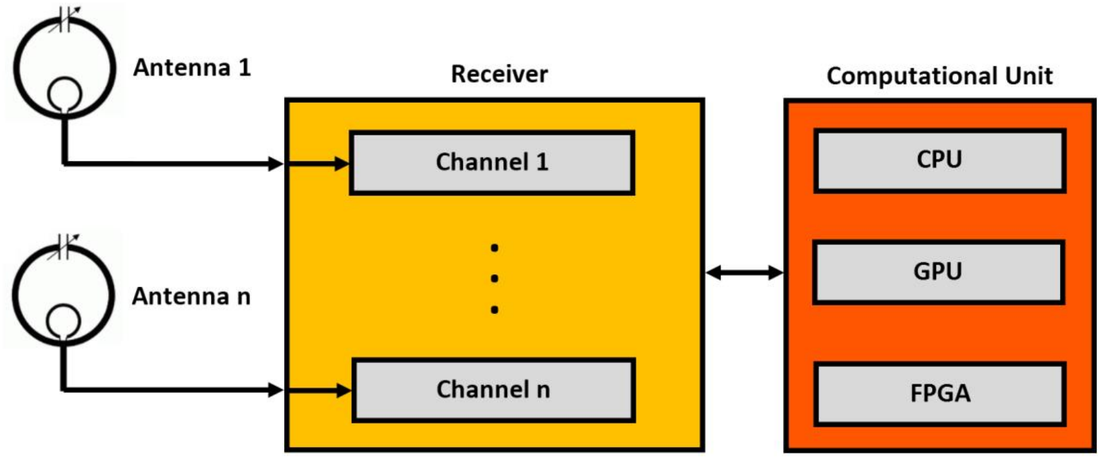

Fig. 2. Each passive radar station consists of several antennas, multichannel radio receiver and computational unit. The latter encompasses a central processing unit and auxiliary hardware for acceleration of the computations.

A novel multistatic passive radar for ionospheric observations

Our system is designed to work in the FM broadcasting commercial radio band occupying the frequencies between 87.5 and 108 MHz. A special antenna has been devised with advantageous properties (see Fig. 2) – a mechanically articulated and electronically tuned magnetic loop antenna. Our radar system is a network of stations interconnected over the Internet (see Fig. 3). Each station can work independently from all the others. Each station is essentially a standalone multistatic passive radar relying on several FM commercial broadcasting transmitters emitting at different frequencies and from different locations. The transmitters of opportunity are chosen according to the signal coverage, power and frequency through a dynamic process.

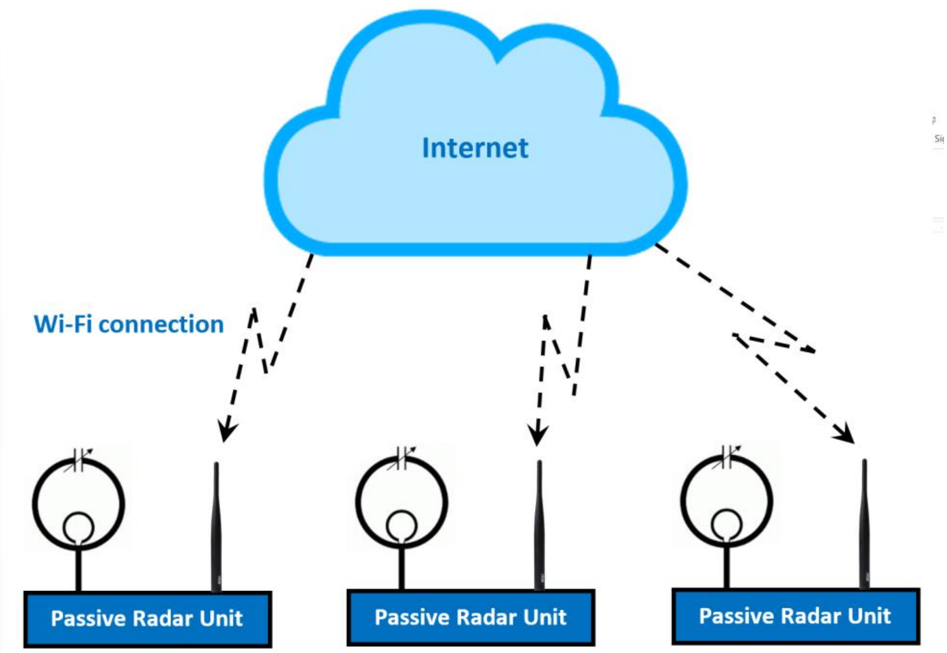

Fig. 3. The passive radar system may be organized as a network of units (stations) communicating with each other over the Internet

To be able to receive more than one transmitter signal simultaneously, each receiver employs several receiving antennas (see Fig. 2). Receivers are of a multichannel design. Magnetic loop receiving antennas are used for their superior qualities in regard to the passive radar operation. The receiver picks up both the reflected and direct signals from transmitters of opportunity. After reception the signals are digitized and processed through digital signal processing in a computational unit. Such a system exhibits enormous computational demand. The extracted information from the signal that characterizes the observed objects is related to the computational power of the system. Hence, to realize the computational unit adequately, special hardware and software are needed. In the recent years, low cost, low weight and low power consumption supercomputing hardware started to appear on the market. It can be engaged in the radar computational unit. Such hardware, apart from fast multicore central processing units (CPUs), are the graphics processing units (GPUs) and field-programmable gate arrays (FGPAs).

Special attention should be payed to the FPGAs because their advantage is manifested when implementing large number of similar very simple operations in a parallel algorithm (see Fig. 4).

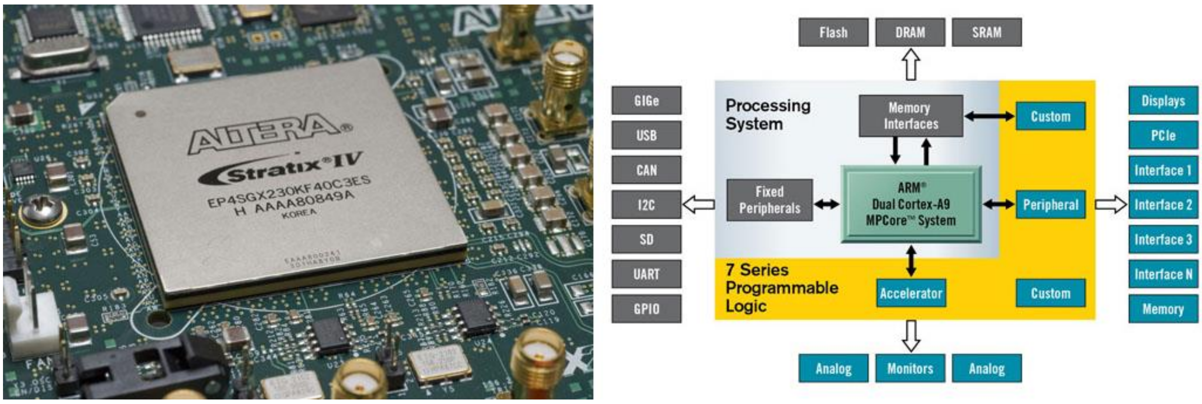

Fig. 4. FPGA hardware applicable to passive radar systems. On the left: Stratix FPGA chip from Altera – *Altera Corporation, CC BY 3.0 <https://creativecommons.org/licenses/by/3.0>, via Wikimedia Commons*; on the right: a Xilinx Zynq 7000 development board block diagram – *Xilinx Inc., CC BY-SA 3.0 <https://creativecommons.org/licenses/by-sa/3.0>, via Wikimedia Commons.*

The employed VHF band

There are well defined criteria for choosing the working band. The FM broadcasting commercial radio band between 87.5 and 108 MHz is in the VHF range (30 to 300 MHz). There is a rule of thumb implying that for ionospheric observations the lower the frequency the better the reflection shall be. This rule is true for frequencies as low as the top of the HF band. Apart from the FM broadcasting transmitters there are no other transmitters of opportunity working in VHF or HF bands and located in the region of Bulgaria – where the first prototype shall be installed. Yet, there are a number of FM broadcasting transmitters in our country with powers of 10 kW.

Table 1. Transmitters of opportunity in the region of the city of Sofia

Transmitter	Location	Frequency	Power
Bulgarian National Radio *Hristo Botev*	Kalofer, radio-relay and television station – Botev Peak, Bulgaria	92.20 MHz	10 kW
Bulgarian National Radio *Horizont*	Kalofer, radio-relay and television station – Botev Peak, Bulgaria	100.90 MHz	10 kW
Bulgarian National Radio *Hristo Botev*	Vitosha Mountain TV Tower – Kopitoto Peak, Bulgaria	92.90 MHz	10 kW
Bulgarian National Radio *Horizont*	Vitosha Mountain TV Tower – Kopitoto Peak, Bulgaria	103.00 MHz	10 kW
Bulgarian National Radio *Hristo Botev*	Berkovitsa, radio-relay and television station – Petrohan Pass, Bulgaria	99.50 MHz	7 kW
Bulgarian National Radio *Horizont*	Berkovitsa, radio-relay and television station – Petrohan Pass, Bulgaria	101.40 MHz	10 kW
Bulgarian National Radio *Horizont*	Kyustendil, radio-relay and television station – Viden Peak, Bulgaria	102.10 MHz	10 kW
Radio and Television of Serbia, Radio Belgrade 1	Pirotski Crni Vrh, Serbia	98.5 MHz	15 kW
Radio and Television of Serbia, Radio Belgrade 202	Pirotski Crni Vrh, Serbia	101.0 MHz	15 kW
Radio and Television of Serbia, Radio Belgrade 1	Rosomač, Serbia	93.4 MHz	15 kW
Radio and Television of Serbia, Radio Belgrade 1	Dimitrovgrad, Serbia	94.2 MHz	15 kW
Radio and Television of Serbia, Radio Belgrade 1	Basara, Serbia	98.8 MHz	15 kW

For example these are the state owned broadcasting transmitters emitting the Bulgarian National Radio (BNR) programmes *Horizont* and *Hristo Botev*. The neighbouring countries also offer transmitters of opportunity. A good example are the transmitters in Serbia located not far away from the Bulgarian-Serbian border at high elevations. Table 1 summarizes some of the available transmitters of opportunity mostly suitable if the passive radar station is located in the area of the city of Sofia.

Conclusion

The passive radar has numerous applications of which greatest significance for us is presented by the scientific application in ionospheric remote sensing. Our novel design of a multistatic passive radar follows our knowledge and experience gained during the development of radioSolariz solar radio telescope www.radiosolariz.space. We aim at finalizing the prototype development and performing initial tests in the coming months. For the future we anticipate tests with different types of antennas and computation acceleration hardware.

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