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# The use of radar for object detection in vegetated regions

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## Abstract

The FOPEN radar uses frequencies at VHF and UHF to penetrate the foliage of trees or buildings and detect bodies and people hiding under their cover. FOPEN is an important technology, being located on airborne and ground-based platforms and designed to aid surveillance of very large areas, especially those areas rich in vegetation, which are unsuitable for detection and identification using other sensors. The information the FOPEN radar provides ensures the necessary support for civil or military activities. The civilian use of FOPEN ensures the fulfillment of surveillance and monitoring missions of the Earth's surface. The data provided will ensure the study of biodiversity, forests, land surface, etc. through the potential of this radar to detect bodies under the canopy of trees.
The military use of FOPEN ensures the detection of enemy forces and assets concealed under foliage, whether they are moving or not. The images generated by FOPEN ensure the detection of targets by electromagnetic waves penetrating foliage or buildings, countering adversary camouflage, concealment, or deception techniques. The data provided by FOPEN ensures the necessary information support for decision-making processes during mission planning and execution.

**Keywords:**
air surveillance; FOPEN; active sensors; air surveillance systems; ultra-wide sensors.

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Acquaintance with the situation on the battlefield has been a permanent concern of commanders throughout the history of armed confrontations that have accompanied the evolution of human society. The aim was to know in advance the movements of the adversary in order to take the necessary measures to counter his actions and to ensure through one's own forces tactical superiority in order to achieve victory.

At the same time, they sought to conceal the actions and presence of their own forces in the battle area through the intelligent use of the physical characteristics of the terrain and vegetation (especially forests). Thus, the actions taken by the commanders were aimed at taking concrete measures for the permanent research and observation of the actions of the adversary, on the one hand, and for concealing or hiding the forces, means, or action intentions of the own forces against the opponent, on the other hand. If before the 20th century, the tasks of observing and analyzing the adversary were accomplished by people specially trained to collect information about it, the beginning of the century brought to the fore technological achievements that offered the possibility of surveillance and detection of enemy forces and military assets. In this regard, we can mention the radar, as well as a wide range of passive sensors (thermal, optical, acoustic, etc.) with superior detection capabilities, capable of locating and identifying the forces and military assets placed in an area of interest.

The evolution of science and technology has led, in the last five decades, to the creation of passive and active sensor systems capable of detecting a varied range of threats to self-defense forces. The deployment of sensors on a wide range of platforms (space, air, land, and sea) has contributed to increasing their potential to respond to commanders' requests to provide the necessary information support for the military decision-making process. The information support requirements requested by the commanders, and the concrete needs for surveillance of the military space operations during armed conflicts contributed to the identification of new theoretical principles for the design and development of revolutionary active or passive sensor systems, capable of detecting the forces and the military assets of the adversary in conditions, places, environments, etc. in which they could not be discovered before their appearance. One example of this is the US military's request to find technological solutions capable of detecting the armed forces and military assets of Vietnamese guerrillas operating under the cover of the tropical jungle. The characteristic of electromagnetic waves with frequencies below 1 GHz to propagate effectively through vegetation, especially through forests, was known prior to requests from the US Army, but these did not materialize through scientific research to provide a radar system capable of detecting the armed forces and the military that used vegetation to hide their presence and intentions of action. The studies launched in the middle of the seventies ended, after almost a decade of research and experimental verifications, in obtaining a radar capable of penetrating the vegetation and discovering living things or moving objects. This radar is mentioned in the specialized literature as FOliage PENetration-FOPEN or Foliage Penetration Radar-FPR (Amato, et al. 2013).

The ability of sensors to detect and determine the movements of people and objects under the cover of vegetation is of high importance both for military and civilian applications, their contribution to increasing the security level of a state being relevant. FOPEN represents, from this perspective, a qualitative leap, with major contributions in ensuring a stable security environment through the information provided to the structures with responsibility in this field. This technology can detect and monitor discreetly, without being able to be detected, the presence of people acting under the cover of vegetation or buildings from large distances, on the order of tens of kilometers, constituting a powerful tool in combating or neutralizing threats to the security of a state. Military personnel operating in conflict zones, as well as law enforcement personnel, face dangers and threats generated by the possibility of the existence, on the one hand, of adversary combatant structures or, on the other hand, of criminals hidden in buildings, behind the walls, trees, or bushes. Their detection and location with the help of FOPEN provides the information needed to plan and carry out effective actions to neutralize both military and civilian threats.

In this study, I will present the importance of FOPEN in providing information support, the theoretical principles underlying the development of this radar, the importance of the data provided for an effective decision-making process, as well as increasing the safety level of the forces during the performance of missions, both in the military and civilian fields.

## Brief History

The military confrontation imposed the surveillance of the battlefield, being considered a necessity of utmost importance. Knowledge of the existing situation during military actions always constituted a pressing and permanent need for every commander. Using the balloon in battlefield surveillance missions allowed them to know the enemy's situation at much greater distances and with much better precision than any ground observer. Due to the technical and scientific evolution of the beginning of the 20th century, aircraft were used as a means of combat and surveillance, as well as the RADAR, as a specialized means of detection, capable of detecting the adversary attack on the sea or in the air.

Compared to the aircraft that successfully took over the surveillance missions carried out with the help of balloons, increasing the surveillance distance, and increasing the accuracy of the information about the adversary, the radar did not generate much interest from either the scientific community or the army, due to the fact that the existing technology did not allow the creation of a detection system considered to be relevant from the military perspective.

The increase in aerial surveillance possibilities with the help of aerostats or aircraft had the effect of diversifying the actions carried out by the belligerents to counter the existing surveillance capacity. Therefore, there were adopted measures in order to conceal the armed forces and military assets or the maneuvers carried out in the tactical field, with the aim of preventing the adversary from knowing their intentions and the objectives of the missions. Decreasing the effect of the air attack was achieved by moving in conditions of low visibility, creating smoke screens or artificial fog to cover the combat device, using the relief or vegetation to cover the troops, etc., with the aim of reducing the possibility of being discovered from long distances.

Research undertaken in the interwar period demonstrated the possibility of detecting maritime vessels and aircraft using electromagnetic waves. The Daventry experiment, carried out in 1935, was the culmination of several decades of research, and consisted in demonstrating in practice the radar's ability to detect air attack means. Until World War II, RADAR technology had advanced enough, being able to detect and locate aviation and naval assets at long enough distances in order to combat them. In this regard, when the war broke out, both belligerent powers, Great Britain, and Germany, had well-organized airspace surveillance systems capable of carrying out specific missions and providing the information necessary for the conduct of air operations.

However, technological development did not allow the creation of radars that would allow the detection of ground targets and the permanent surveillance of the ground battlefield, the methods used in the First World War for the concealment, masking, and protection of ground forces under the cover of relief or vegetation remained the effective ways to counter aerial surveillance of ground combat equipment. The reasons behind the impossibility of the radars built during this period to detect land targets or the military assets covered by the vegetation were of a technical nature, generated by the lack of a stable waveform and a rudimentary technology for processing the signal reflected by the objects in their path.

At the beginning of the seventh decade of the last century, the US Army developed the first battlefield surveillance radar system, namely the side-looking radar AN/APS-94 (Side-Looking Airborne Radar-SLAR), located on an aerial platform OV-1 Mohawk (Rosenfeld and Kimerling 1977, 1519-1522). The radar was placed on the OV-1B Mohawk variant, developed by Grumman Aircraft as an aircraft intended for radar surveillance missions of the land surface, video, and photo observation (FAS n.d.) in order to obtain information regarding the location of military camps, mechanized artillery units. The Vietnam War marked the deployment of the first tactical battlefield surveillance missions using radar, where the US military sought to obtain a clear picture of the movement of enemy forces and assets. The data provided by this type of radar did not ensure the detection and identification of guerrilla forces hiding in rural areas, in the tropical jungle, or in complex underground gallery networks, from where they managed to launch surprise assaults. As a result of these actions, following the reports and requests of the commanders in the field, research was initiated on the development of radar systems capable of detecting the armed forces and military means of the adversary that were moving under the cover of the jungle. Coincidentally, in September 1964, two students of the University of Rochester, USA, Louis V. Surgent Jr., and G. M. Foster, were studying the possibility of using some fundamental concepts of theoretical physics in making the distinction between civilians and combatants. Their research was focused on the possibility of detecting combatants under the cover of the jungle and identifying those people who possess weapons. The results of the research demonstrated that there was the possibility of electromagnetic field penetration through foliage and detection of armed or unarmed individuals hidden in the jungle or areas rich in vegetation. Based on the results obtained, the two students presented to the US Army, in October 1965, a proposal for a project entitled "ORCRIST, An Anti-Guerrilla Detection System", marking the beginning of the development of the radar capable of detecting military forces and assets acting under the cover of vegetation. The program started within the US Army Land Warfare Laboratory, in Aberdeen, Maryland, and took place between May 1966 and June 1974, having as the final goal the appearance and development of new radar systems such as battlefield surveillance radar, penetration radar of foliage disposed on aerial platforms, surveillance of military objectives, etc. (Surgent 1974)

The FOPEN radar realized during this research stage was functionally limited due to the impossibility of detecting and locating static objects under the cover of vegetation. As a result, concealed combat equipment, engineering works, buildings, camps, personnel, and protection equipment structures, etc. could not be detected and neutralized. This variant constituted a technology used for the detection and indication of moving ground targets, known in the literature as GMTI (Ground Moving Target Indication) radars. The GMTI radar was used by the US military in operations conducted in Southeast Asia during the Vietnam War, but the impact of this detection system on the conduct of military actions was reduced due to the tactics adopted by the Vietnamese guerrilla forces. Considering the characteristics of the military actions carried out by the Vietnamese troops, there was a request from the leadership of the US army to identify a technological solution that would allow the detection of the enemy's military assets, engineering works, camps, etc. set in the tropical jungle. A suggested solution was to use a synthetic aperture radar operating in the VHF and UHF frequency bands used for FOPEN. The radar thus obtained, known in the literature as FOPEN SAR (Davis 2011, 4), would have eliminated the technological limitation of the FOPEN radar, namely the impossibility of detecting bodies and static objects, ensuring the provision of the necessary information to identify and neutralize the Vietnamese combat ground forces hidden in the jungle. However, the existence of several technical impediments, namely the high resolution of some tens of meters as well as the dimensions of the SAR FPR that required the use of a large aerial platform with minimal chances of survival in the conflict zone, the difficulties encountered in data processing and obtaining imprecise images led the military leadership to abandon the development and use of the FPR SAR.

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The second stage of FOPEN development took place in the period between the end of the 9th decade and the middle of the last decade of the last century and was achieved through the involvement of the MIT Lincoln Laboratory in this project, under the technical leadership of Dr. Serpil Ayasil (Davis 2011, 9), as well as through the testing of these radar systems in two independent programs, respectively FOLPEN of the Stanford Research Institute under the leadership of Roger Vickers and CARABAS of the Swedish Defense Research Establishment under the leadership of Hans Hellsten (Davis 2011, 9). Around the same time, several test programs were initiated and financed for the potential of FOPEN, which aimed to achieve complementary objectives of scientific and military research. The results of these tests provided an understanding of the importance of the choice of frequency, polarization of the wave, elimination of interference, and the characteristics of the signal distortion caused by tree foliage (Davis 2011, 9), having the cumulative effect of increasing the efficiency of the detection of objects or living beings in motion or at rest under the cover of vegetation. It should be noted, that during this stage of development and testing of FOPEN, the scientific contribution and financial support provided by the Defense Advanced Agency of the research projects within the development program of this technology, carried out over a long period, under the guidance of some prestigious personalities in the field of scientific research such as Dom Giglio, as coordinator from 1988-1995, Mark Davis, as coordinator from 1995-1998 and Lee Moyer, as coordinator from 1999-2005 (Davis 2011, 9).

Another stage in the development of FOPEN occurred at the beginning of the 21st century, characterized by the influence of information and communication technologies on the evolution of this radar system. Technological developments in the field of digital signal processing have allowed increasing the radar's ability to discover objects under the cover of vegetation, by reducing the impact of the signal distortion caused by tree foliage on the detection of bodies or objects. These technological developments brought FOPEN technology to the attention of military leaders, noting the immense potential of this radar in providing information from an environment that until a century ago was impenetrable. The technical possibilities provided by the research results obtained in the last two development stages of the radar ensure the provision of specific information that will contribute to the realization of a real, accurate, and complete operational image of the terrestrial battlefield, eliminating the uncertainty generated by the existence of forests and rich vegetation regarding the manner of deploying armed forces and conducting military actions.

## Physical Phenomenon Description

Given the above on the history of FOPEN development, an increase in interest in this technology can be identified, starting from 1990. The implementation of achievements in the field of information and communication technology have contributed to increasing the potential of this type of radar to provide the data necessary to carry out scientific research on the Earth's surface (biodiversity study, land surface, forest areas, ecology, etc.). At the same time, the development of the FOPEN radar ensured the obtaining of higher quality data compared to those of the 70s-80s, thus contributing to the increase of the military's interest in using this type of radar in surveillance and research missions of areas of interest. Therefore, several tests were funded and carried out to collect data from different areas of the Earth in order to increase the reliability of the FOPEN radar. Extensive research was conducted to determine the effects of foliage on the radar's ability to detect and track people or objects in forests or areas rich in vegetation. Tests carried out in various areas of the globe to determine the influence of jungle, arctic forests, or various types of vegetation have helped to identify the effects that occur during the interaction between electromagnetic waves and vegetation (Gallone 2011, 173-175).

The first effect identified as a result of this interaction is the attenuation of the radar signal. The attenuation of this signal is produced both by the phenomenon of absorption of electromagnetic waves and by the phenomenon of scattering that occurs when electromagnetic waves propagate through the forest foliage. The studies undertaken revealed that the high density of the forest foliage generates a greater attenuation of the signal. Therefore, higher values of the attenuation of the electromagnetic wave were recorded in the jungle area compared to the attenuation produced by the forests in the northern areas. Another conclusion that emerged from these studies was that signal attenuation had different values depending on the frequency of the electromagnetic waves, with minimum values for the VHF frequency range (Amato, et al. 2013, 194).

Another effect identified was that of the polarization of electromagnetic waves. This effect arises due to the reflection of electromagnetic waves by trees and is associated with the scattering phenomenon. The tests showed a dependence of the attenuation phenomenon from that of the polarization, namely the horizontal polarization adds more attenuation compared to the vertical polarization (Amato, et al. 2013, 194).

Another effect identified was the phase shift of the radar signal. The propagation of electromagnetic waves through the tree canopy is assimilated to the propagation through a non-uniformly distributed medium that generates a random variation in the signal. This phenomenon of random phase variation affects the radar's ability to detect a target located on the ground surface under the cover of the forest (Amato, et al. 2013, 194).

Another important effect influencing the radar signal is that of diffuse reflection of the radar signal back to the sensor. This diffuse reflection is generated by the scattering phenomenon that occurs when waves propagate through compact and large foliage. It should be considered that the resolution cell of the FOPEN radar is generated by the limits of the spatial resolution and the angular resolution, where there are wind blow trees, both fixed elements (rocks, tree trunks, ground) and mobile elements (leaves, branches) that will generate the phenomenon of scattering of electromagnetic waves and their diffuse reflection towards the sensor. Consequently, the radar signal reflected to the sensor will contain a static component and a variable component of the diffuse reflection phenomenon (backscatter) which, together with the phenomenon of attenuation, phase shift, and polarization, reduce the efficiency of normal processing techniques based on the Doppler phenomenon, with impact on the radar's detection capability (Amato, et al. 2013, 194). The reflection of the radar signal by an object is a complex phenomenon that depends on the electromagnetic properties of the object and its geometry. Within the resolution cell we find, therefore, the signal reflected by the object and the phenomenon of diffuse reflection of the radar signal coming from the foliage of the trees, whether the wind blows through them or not, the combination of which results in a statistical variability that contributes to the reduction of the detection capability of the radar (Ulander 2004).

Given the above, the impact of the aforementioned effects must be taken into account in order to improve the detection capacity of the FOPEN of the objects disposed in the foliage or under the canopy of the trees. The clutter phenomenon, created by electromagnetic wave scattering upon contact with vegetation, can make it difficult to detect personnel and vehicles that reflect small values of radar pulse power. The elimination of the shortcomings generated by the radar scanning of areas rich in vegetation has known several stages that were based on many experiments carried out in the field, in order to understand the interaction between dense foliage and electromagnetic waves, aiming at increasing the efficiency of the FOPEN radar. A first step was achieved in the first phase of FOPEN radar development when two innovations were identified to be necessary in increasing the radar's detection capacity, namely the creation of transmitters to generate coherent electromagnetic waves, related signal processing systems as well as the arrangement of the radar on dominant elevations in the terrain, masts, or high towers in order to correct the attenuation effect of the radar signal generated by the tree foliage (Davis 2011, 4). Another relevant aspect in the development of FOPEN was the identification of the optimal frequency band to ensure a minimum attenuation of the radar signal, namely the VHF band (Ulander 2004, 19-20).

## The Use of FOPEN Radar

The progress in sensor technology and information and communication technologies in the 21$^{st}$ century will ensure a qualitative leap in the development of information, surveillance, and reconnaissance systems. The development of these technologies will enable the implementation of active and passive sensors with improved technical parameters that will allow the detection of low-reflective targets.

The use of camouflage techniques and vegetation, particularly dense foliage on the battlefield by the combatant, has highlighted the deficiencies of the current ISR systems in detecting and locating targets. The increase in the performance of the sensors, and the quality of the data provided, will be achieved through a much wider use of the electromagnetic spectrum. In this sense, ultra-wideband (UWB) technology ensures a much more efficient use of the electromagnetic spectrum for various applications, such as video transmissions, voice, and data transfer or for locating objects. Ultra-wideband systems are made with different architectures and can operate with continuous or pulsed emission, depending on the applications where they are used. Among the applications where this technology is used, we may mention:

- *„UWB can be used to quickly send large amounts of data between devices. For example, UWB can be used in conjunction with 5G networks to offer faster speeds and greater bandwidth.*
- *low latency communication: UWB is suitable for low latency communication due to its short transmission period and small packet size. This makes UWB ideal for applications such as gaming, where low latency is critical to maintaining a smooth gaming experience.*
- *UWBPS: UWB can also be used for positioning and tracking purposes. UWBPS uses ultra-wideband to calculate the location of objects in real-time. This makes UWB an attractive option for applications such as automotive safety and collision avoidance. UWBPS can also be used for security applications such as tracking people or objects.*" (Isak 2022)

From the above-mentioned information, it results that the following advantages of broadband technology are: low latency, high precision positioning, high data transmission rate, low energy consumption, multiband support, low risk of interference, and security in data transmission.
Due to the high data transmission capacity, ultra-wideband technology will be able to be used in the future for a variety of purposes, including:

- *„connecting wireless devices;*
- *delivering high-quality videos;*
- *improving data security;*
- *facilitating communication between vehicles and the infrastructure around them;*
- *motion detection in congested areas.*" (Isak 2022)

Ultra-wideband sensor systems will provide an obvious operational advantage because it will be difficult to take measures to protect a target using a very wide bandwidth. Within this sensor category, ultra-wideband radar represents a new stage in radar development by upgrading to the generation of broadband or ultra-wideband pulses. This aspect allows the use of much lower pulse power which makes the radar emitter difficult to detect. A specific feature is the signal bandwidth, which is at least 25% of the value of the carrier frequency, compared to previous narrowband radars whose signal is 10% of the value of the carrier frequency. Ultra-broadband radars will constitute the next qualitative leap of FOPEN, ensuring

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the obtaining of the most accurate information about objects or people hidden in areas rich in vegetation. Another method of obtaining high-quality, comprehensive information about an area of interest is to dispose of long-range sensors on ground-borne, airborne, and space-borne platforms in order to carry out the surveillance of the area of interest.

The collection of data by sensors depends on the way they are processed. The developments in the field of information and communication technologies have allowed the implementation of new data processing algorithms, contributing to the diversification of sensor types but also to the implementation of new threat detection ways. In this sense, the design of the sensors aims to satisfy the future requirements of the processing systems on the fusion between the data and the operational requirements on the knowledge of the battlefield environment. The fusion of data obtained from surveillance and reconnaissance missions of an area of interest, and their integration into a precise operational picture must ensure the detection and identification of threats against own or allied forces. One such example is the integration of the FOPEN radar with GMTI in a system that offers the possibility of locating, under conditions of fog, rain, and dust storms, almost any land target, even if it is under the cover of vegetation, providing high-resolution images to be used by military decision makers (Lockheed Martin 2012).

An important aspect is the correlation of data provided by several types of sensors, disposed on different types of ground-borne, airborne, and space-borne platforms. The data provided by the FOPEN radar placed on airborne or ground-borne platforms will be correlated with the data provided by the other categories of sensors with the aim of generating a final product needed for the commander in decision-making and mission planning. The correlation of the data provided by the sensors requires their integration in an increasingly complex architecture, supported by the sensor network, whose purpose consists of a better knowledge of the existing battlefield environment (Ackerman 2010).

Another field of applicability of the FOPEN radar is that of perimeter surveillance, critical infrastructure protection, national borders protection (against illegal immigration, drug trafficking, cross-border crime, etc.), providing information on the activity of people involved in actions that bring prejudices to the state, carried out in complex environments, under the cover of the forest, jungle, or other types of vegetation.

The civilian missions carried out by the FOPEN radar are multiple, combined with the surveillance actions carried out with other categories of sensors. It includes:

- *disaster preparedness and response;*
- *emergency rescue;*
- *wildlife monitoring and tracking;*
- *military surveillance;*

- *border security;*
- *search and rescue operations;*
- *operations to combat drug trafficking;*
- *forest fire monitoring*." (IMSAR n.d.)

The use of several categories of sensors, active or passive, ensures a high level of precision because these systems complement each other, providing the necessary data for the generation of a real-time image of the monitored area. From the military perspective, the data provided will contribute to the knowledge of the battlefield environment, providing information about moving targets, vehicles, and people, as well as about fixed assets of the adversary's equipment that are located and act under the cover of vegetation, ensuring their detection through the dense foliage of the jungle or temperate and boreal forests. Detection capabilities through high-density foliage will provide commanders with the information needed to identify and hit targets located in areas that were considered secure. From a civilian perspective, this radar's ability to detect ground objects through high-density foliage makes it ideal for scientific missions to research, study, and monitor the Earth's surface. FOPEN radar can be also used in the areas of border security, cross-border crime, and harbor activities or can support the activity of law enforcement agencies in identifying and apprehending criminals hidden in buildings or under the cover of vegetation.
From the above-mentioned information, it results that FOPEN radar is a technical system with multiple uses that will contribute, through the data provided, to ensure a secure climate suitable for human activities.

## Conclusions

The FOPEN radar is a relatively new sensor in surveillance and research activity, with relatively modern detection capabilities, able to perform a wide range of missions, both military and civilian. It is an innovative radar with unique capabilities that provides continuous surveillance through high-density foliage and tracking targets in the areas of interest in big areas. The FOPEN SAR radar operating in the VHF band will ensure the detection of targets hidden beneath foliage, such as a truck, artillery pieces, etc., which are difficult to detect in the absence of this technical system.

Operationally, the use of this radar by military structures or other structures with responsibilities in the field of national security ensures the permanent detection and tracking of all fixed or mobile targets in the area of interest, such as people or vehicles in motion.

Militarily, the FOPEN radar will provide real-time knowledge of the battlefield, ensuring the detection of enemy assets and military forces hidden in the forest or jungle, providing the information necessary to attack the enemy's objectives and detect moving targets, especially those hiding under the cover of high-density foliage. The data provided will ensure the necessary informational support for the military decision-making process during mission execution. At the same time, the ability of this radar to detect static or moving objects through the dense foliage of the forest allows its use in monitoring missions and studying the land surface, providing information regarding biodiversity, land surface, forested areas (dimensions, location, arboretum, etc.), in ecology, environmental sciences, etc.

The FOPEN radar, used simultaneously with other types of active and passive sensors, will timely ensure, through the data provided, the identification of events or phenomena with an impact on human activity, contributing to obtaining and maintaining an optimal climate of security for the development of social life.

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