CENTRE FOR JOINT WARFARE STUDIES

CENJOWS

FOLIAGE PENETRATING RADAR - USE OF SYNTHETIC APERTURE RADAR

Lt Col Vivek Gopal, **a graduate of the National Defence Academy, was commissioned in December 2000. A MTech, paratrooper & certified Project Management Associate, the officer is presently posted as Instructor at a premier training establishment.**

Introduction

While significant development has been made in enhancing the surveillance grid by employment of a variety of sensors on our borders, significant progress is yet to be made in the field of foliage see through or foliage penetration radar (FOPEN or FPR). This becomes even more pertinent when we are employing sensors along our Northern borders where the tree line becomes thin only in the snow desert sector. Majority of the geography in the valley lends itself to heavy coniferous vegetation & thick under growth. Such dense vegetation is used for camouflage & concealment by anti-national elements/ rogue elements to infiltrate. There is hence a need to understand the utility of FPR & how it can be gainfully employed. The aim of this paper is to acquaint the readers with FPR techniques & basics of associated technology.

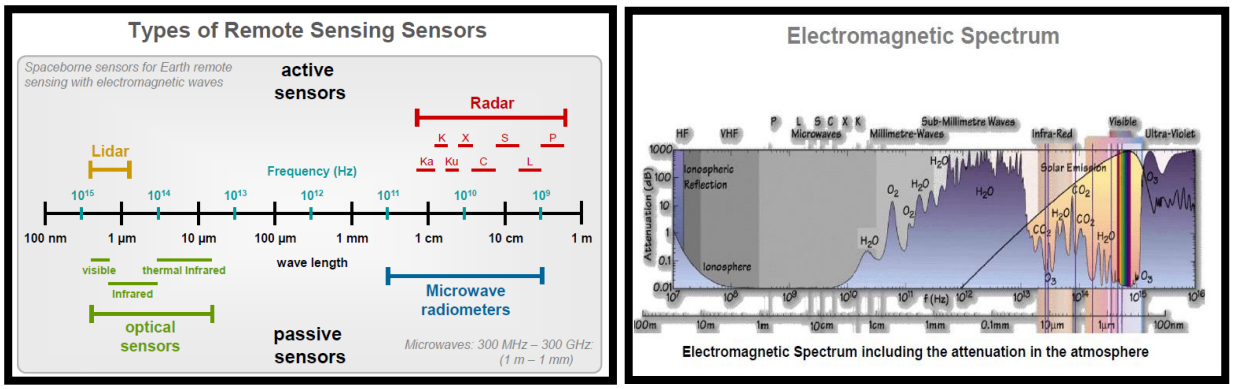


Fig.1 - An Overview of the Electromagnetic Spectrum

Historical Perspective

The first development of FPR occurred during the Vietnam conflict, where early systems were needed to detect & recognize ground moving targets. Three innovations were in turn needed:-

(a) Coherent waveforms.

(b) Associated signal processing.

(c) Radar Installations on major hills.

These innovations increased the target signal-to-noise & minimized the clutter spread that masked the small returns from personnel & vehicles. FPR has continued to be a developing technology to provide geospatial & military users with detection & characterization of objects under dense foliage. Many areas of the earth are remote & inhospitable for characterization, as well as monitoring the effects of weather, atmosphere & geological changes on the region. Similarly, military commanders want to know about recent construction or tactical maneuvers in an area covered by dense foliage.

RADAR has the inherent ability to characterize a wide area, to assess changes in fixed objects, & to detect & track moving objects. Early RADARs were limited to detection & tracking of objects by the attenuation & scattering of clutter between the RADAR & the features being observed. Forests have been particularly difficult environment due to the scattering of the waveforms & severe attenuation at microwave frequencies. Over the

past 40 years, the advances in wave form synthesis have led to finer & more accurate FPRs being developed.

After many trials, it was clear from operation of the foliage penetration GMTI (Ground Moving Target Indication) systems, that if the targets were not moving, it was impractical to detect the important tactical objects—vehicles & structures. A need arose to develop a method of detecting stationary objects, & an evolving technology was the synthetic aperture RADAR (SAR). Excellent cross-range resolution could be obtained with coherent processing of long collections of RADAR data. Early RADARs developed for foliage penetration were in response to military needs to find & locate insurgents in a severe tropical environment (read by US Army for Vietnam operations). Little quantitative data existed to characterize the clutter & propagation losses in this environment. Based on a series of data collections in tropical regions, trials were resorted to for homing onto better system post-validation.

Only the GMTI RADARs were taken to the military operations in South East Asia by the US Army. The development of SAR capability was attempted, but the military planners could not justify the development due to several factors. First, the resolution of FPR- SAR was limited to tens of meters. Operational SAR systems were significantly better than this & were not accepted due to the unreliable image recognition results. Second, the SAR systems were large & could not be carried on aircraft that would survive in a military environment. Finally, the state of the art in real-time signal processing was not mature enough to meet the needs of the mil users.

Scope

The paper covers the aspects of vegetation / foliage as prevalent in our Northern frontiers (mainly the valley) & there by acquaints the readers with respect to FPR & its associated technology which may lend itself useful for future acquisitions. The scope of the paper thus is as under: -

(a) Part I - Foliage/ Vegetation in the valley.

(b) Part II - Need for FPR Technology & Its Development.

(c) Part III - Synth Aperture Radars – Basics.

(d) Part IV - Synth Aperture Radars – Best Suited for FPR.

(e) Part V - Recommendations & Future Potential.

PART I: FOLIAGE/ VEGETATION IN NORTHERN LATITUDES

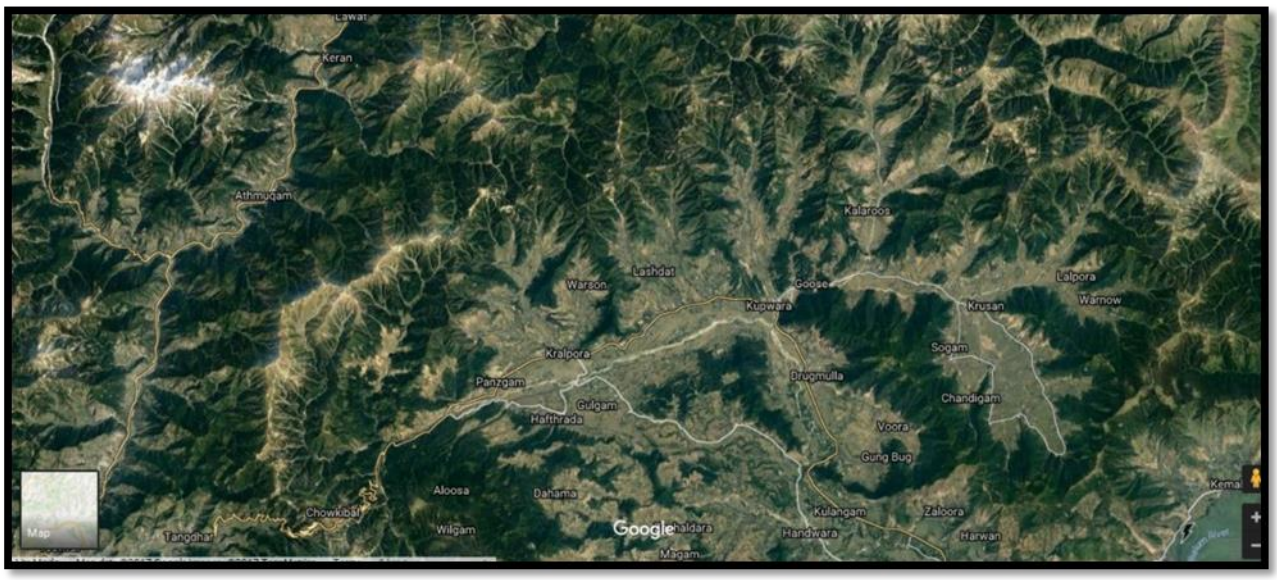


Fig.2- Google Imagery of Area

The area, the species and density of forests are directly influenced by lithology, rock-structure, altitude, aspect of slope, insolation and precipitation. The influence of these physical factors is quite pronounced in the state of Jammu and Kashmir. Consequently, there is great diversity in the natural vegetation as over 4,000 species belonging to 1500 genera are found in the state. The districts of Udhampur (1.63%), Kupwara (8.18%) and Rajouri (6.46%) are the areas in which forest cover is reasonably significant while in the remaining districts little or very little area is under forest. Being situated at higher latitudes and characterized by undulating and mountainous topo, most of the forests of the state of Jammu and Kashmir belong to the coniferous category. In the valley floor of Kashmir, poplar, chinar, maple and vir (willow) are the main species of vegetation which are deciduous in character. Where soil conditions permit, mixture of broad-leafed deciduous trees, such as maples and oaks, grow together. The thick undergrowth in the forests stores up rain water and allows it to flow slowly and that is why rivers that have their sources in the forests do not run dry in the dry seasons and check floods during the rainy season.

Soils. In the regions of Jammu and Kashmir the soils are loamy and there is little clay content in them. Poor in lime but with a high content of magnesia, the soil is treated with chemical fertilisers and enriched with green manure and legume before cultivation. There is sufficient organic matter and nitrogen content in the alluvium of the Kashmir valley as a result of plant residue, crops stubble, natural vegetation and animal excretion.

PART II: NEED FOR FPR TECHNOLOGY & ITS DEVELOPMENT

The early FPR systems were developed for detecting & characterizing objects under both foliage & through ground penetration. The latter capability was important; as demining operations were required after military actions in war-torn areas. In addition, for finding objects that have been hidden, the systems' long wavelengths & polarimetric sensing found usefulness in characterizing land use, land cover, & terrain elevation in many geographic areas.

Significant progress was made in the design of antennas & transmitters for FPR. **The antennas needed to have wide azimuth coverage to enable the requisite illumination angle for achieving the desired cross-range resolution**. They also needed to have an efficient match to the transmit waveform over a very large bandwidth to support the range resolution.

Polarization has found an important place in FPR for characterization of the clutter & objects. Providing Ultra-wide band (UWB) polarimetric antenna was an early challenge. The design of the transmit waveform & match to the antenna was also important to limit the spectral transmission as controlled by the need for frequency allocation constraints.

Every new FPR system development needs to answer the question of using VHF or UHF of operation. Optical photographs & microwave RADARs cannot reliably detect man-made objects that have been hidden in the dense forest cover. Two emerging technologies that could reduce the unreliable detection of targets under foliage are as under:-

(a) The first technology being ultra-wideband (UWB) waveforms that would enable high-resolution SAR images at both VHF & UHF freq.

(b) The second technology utilises of polarization of the RADAR signal in the FPR SAR processing.

All four panes in the figure below are of the same scene; a forested region with several vehicles parked under the foliage & in the tree lines, but collected with different imaging technologies.

(a) On the left is a moderate to high-resolution optical picture, but the vehicles cannot be observed until the sensor is nadir looking.

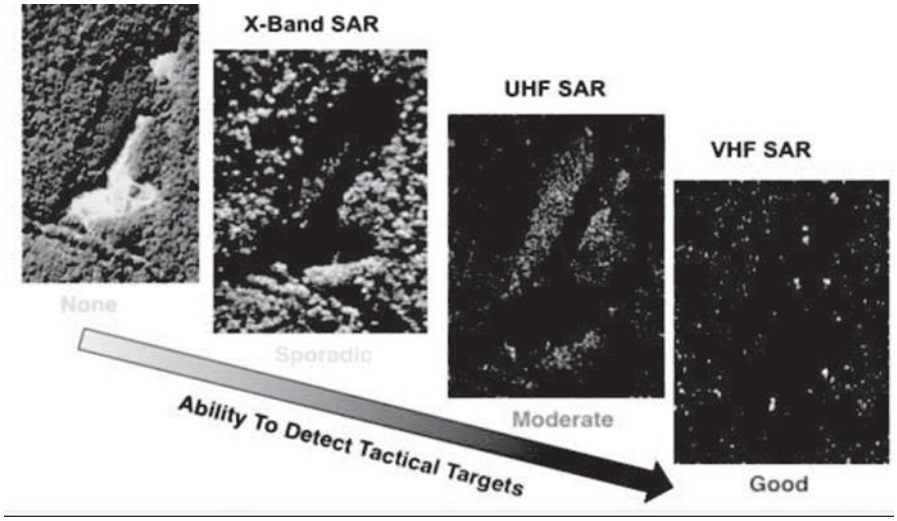


Fig.3 - Different Frequencies Consideration for SAR

(b) The next image to the right is a typical 1-meter resolution X-band image ofthe scene taken on the same day. Sporadic detections were obtained, but only when the glint of targets could be captured in the image.

(c) Neither of these two image products would satisfy the user, especially when high area coverage rate is needed.

(d) The next two images to the right, which are UHF & VHF SARimages, show a more optimistic ability to detect the fixed targets. The **UHF** panel shows images of many of the man-made targets **but high false alarms** with the foliage clutter in the scene.

(e) The detection at **Very High Frequencies** is higher where the **foliage attenuation is significantly lower** & the target cross sections are larger than the clutter. However, **there is limited resolution** (i.e., pixels ontarget) to characterize the objects in the image.

High-resolution imagery serves two purposes:-

(a) Provide a better separation of the object scattering from the background clutter.

(b) Provide more detail of scattering of objects for characterization.

To find a small vehicle or a buried land mine, image resolution is a major consideration. Polarization diversity has been evolving as a significant capability for both target detection & characterization of terrain & man-made objects. If characterization is an important system objective, then polarization must be factored into the system wave form & processing approach from the start. For FPR, higher grazing angles is important for providing less foliage loss & better signal-to-clutter ratio. So, at higher grazing angles the target signal return has the potential to be enhanced relative to the background clutter but with a reduction in ground plane range resolution. **For resolutions under a meter, the required bandwidth is above 150 MHz, independent of any range side lobe weighting**. Figure below, illustrates the importance of bandwidth when compared with the carrier frequency as well as the importance to range resolution.

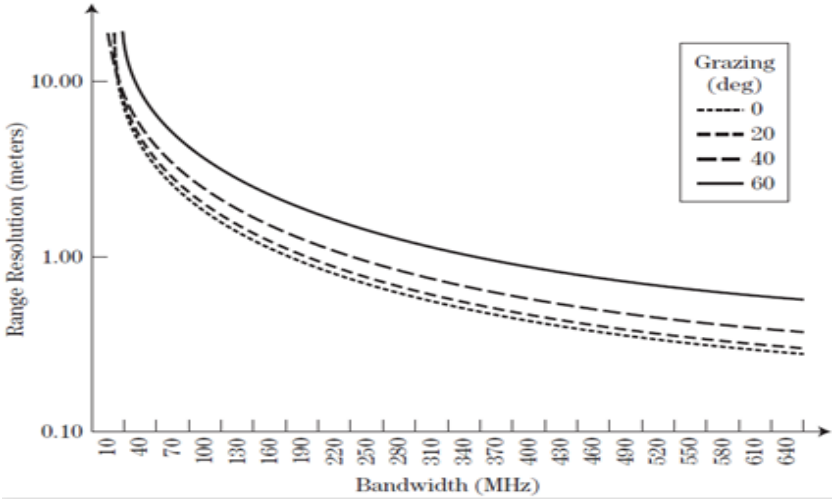


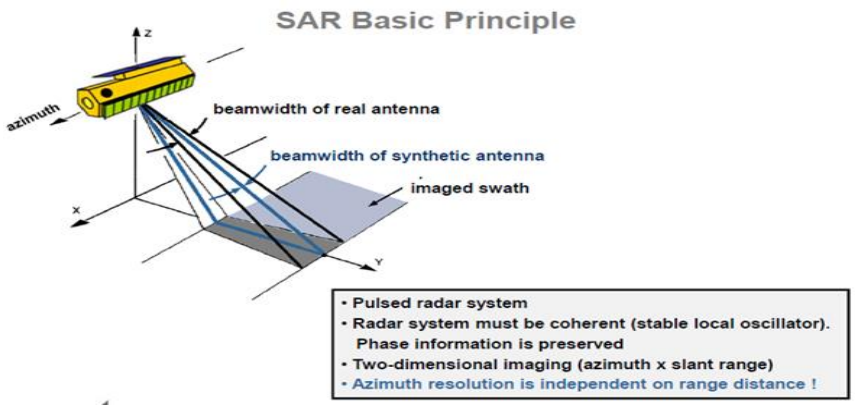
Fig.4 - Effect of Bandwidth & Resolution with Angle of View

FPR has many of the same characteristics as high-resolution microwave SAR, (i.e., wide bandwidth, range curvature, & fine motion compensation for SAR collection geometries). However, to obtain the maximum image resolution, UWB waveforms & large integration angles are required. These extremes in data collection make increased demands not only on the amount of processing for image formation but also on the motion measurement & compensation to focus over the full image &ensure geospatial accuracy.

UHF television & radio stations have always limited the ability to communicate or sense in these RF spectrum bands. It is not possible to avoid these interference (i.e., they are actually jamming) sources because of the spatial & spectral density of the emissions. As a result, techniques are to developed to remove the background interference by waveform design & adaptive processing techniques.

PART III: SYNTHETIC APERTURE RADAR (SAR) – BASICS

SAR has been found to be the best suited technology for FPR. However, it is pertinent to understand the basics include the working principle behind the same. The succeeding paragraph aims to highlight the basics of this technology. **It is also note worthy that FPR can also be considered as an extension of remote sensing**.



The APERTURE is SYNTHETIC i.e. created by the movement of the RADAR which enables greater collection of backscatter.

Fig.5 –SAR Basics

SAR obtains fine resolution for ground images through two effects: -

(a) The **range resolution**, similar to conventional RADARs, is obtained primarily by the **bandwidth of the waveform**.

(b) **Cross range resolution** is obtained by a **physical antenna angular pattern** & the ability to coarsely resolve objects within the real beam. However, for fine cross-range resolution, it is necessary to form a synthetic aperture length by flying a certain length & coherently integrating the returns to obtain the resolution. This is especially true for imaging from VHF & UHF RADAR.

It is pertinent to note that any RADAR will actually be capturing the backscatter as received from objects. To give a brief idea on the back-scatter the following is beneficial: -

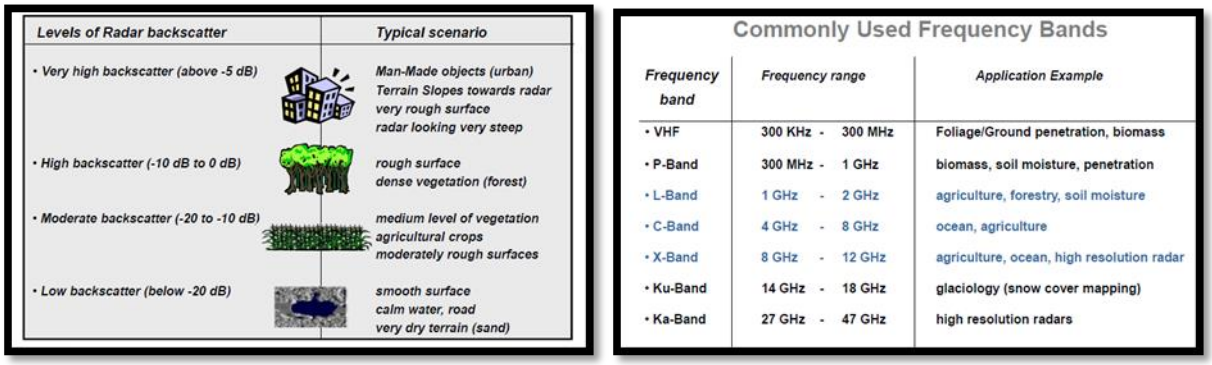


Fig.6 - Employment of Frequency Bands & Backscatter Scenarios

The data flow in SAR is very complex & depends on various factors as well as algorithms used to finally fine tune the image captured. A basic explanation of the system which involves capture of the image & thereafter its 2D formation as visible is as under: -

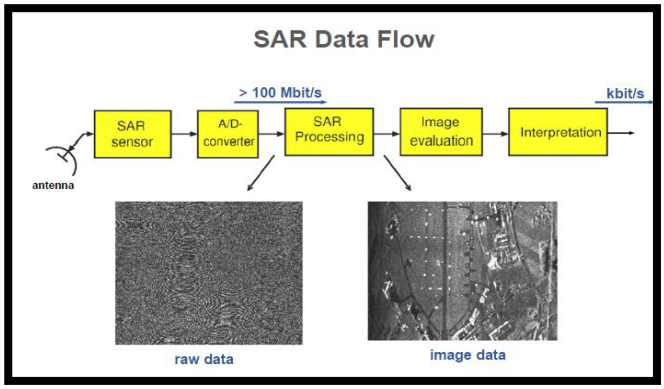


Fig.7 - SAR Image Processing Flow

PART IV: SAR – BEST SUITED FOR FPR

After having seen the technology involved in SAR & its applications it can be well appreciated that SAR will be one of the best suited for FPR. An overview of the properties in summary are as under: -

- High resolution capability.
- Weather independent.
- Day & night functionality.
- Polarization signal can be exploited.
- It can always be complimentary to optical systems in use.
- Terrain topography can be measured.

PART V: RECOMMENDATIONS & FUTURE POTENTIAL

Taking into account the applicability of the RADAR systems & its inherent advantages, the Foliage Penetration Radar (FPR) offers immense potential with respect to counter-terrorist operations (as also counter LWE operations[1]) to include search & destroy missions or any tactical reconnaissance of the area of interest. The same radars when mounted on the rotary wing aircraft for the Army can greatly help in the wide area monitoring & detection (we may extrapolate to UAVs & heavy drones based on payload limitations). Use by the Border Security Force in the Northern Sectors of our country will also be greatly benefited from such a radar[2]. While global firms[3][4]have already forayed into this domain, we are still a few notches behind. FPR-10 (refer image/brochure placed below as on

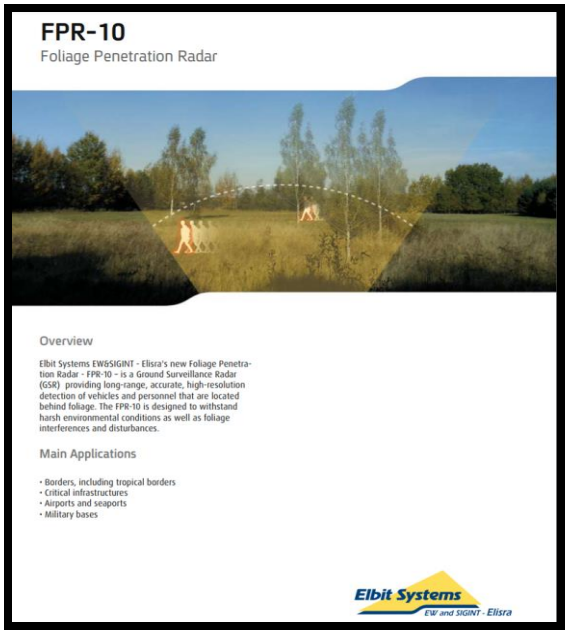
[1]PTI. "Government Plans to Get Foliage Penetration Radar for Naxal Areas." *The Economic Times*, Economic Times, 26 Apr. 2017, economictimes.indiatimes.com/news/defence/government-plans-to-get-foliage-penetration-radar-for-naxal-areas/articleshow/58382883.cms?from=mdr.

[2]Ankit Panda. "India Eyes Israeli Foliage-Penetrating Radar for Kashmir Border Security." *Thediplomat.com*, 20 Aug. 2016, thediplomat.com/2016/08/india-eyes-israeli-foliage-penetrating-radar-for-kashmir-border-security/.

[3]"FORESTER - Foliage Penetration Radar | SRC, Inc." *Srcinc.com*, 2021, www.srcinc.com/products/radar/forester-radar.html.

[4]"TRACER." *Lockheed Martin*, 2018, www.lockheedmartin.com/en-us/products/tracer.html.

manufacture's website) developed by Elisra (Israel) in June 2016[5] has been one such candidate in the past. To give it the necessary impetus, the Defence India Startup Challenge (DISC) has also been launched with the development of FPR as one of the challenges in the year 2020-21.



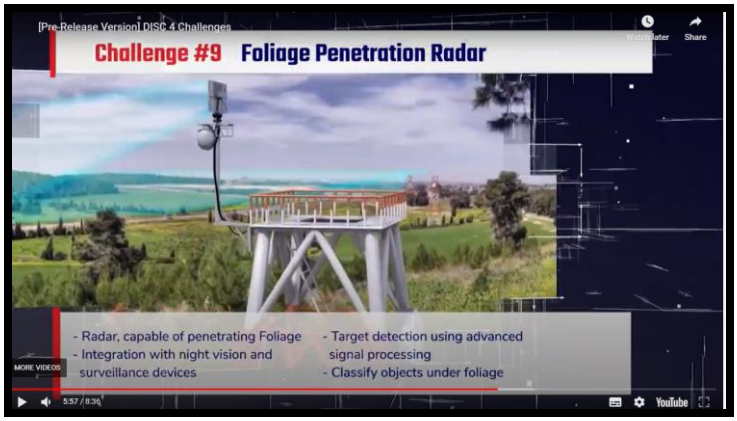


Fig.8 - DISC Challenge – Development of FPR

Whenever developed, the FPR will aid in Reconnaissance, Surveillance, Tracking and Engagement. An airborne radar system will help provide stand-off, persistent, wide-area surveillance for situational awareness of foliage-covered areas. Collaborations with start-ups, IIsT & in-house

[5]"Report: India Is Interested in Elbit's Foliage Penetration Radar | Israel Defense." *Israeldefense.co.il*, 2021, www.israeldefense.co.il/en/content/report-india-interested-elbits-foliage-penetration-radar.

educational/ training institutions will also help in the expedited delivery of such a potent radar platform.

With the existing exploitation of the quadcopters & mini UAVs there is a need to home on to specific FPR based sensors/ payloads which can augment the present-day surveillance capability. In house proposals may be invited from private sector as well as DPSUs which can either help development such a system or aid in miniaturizing the payloads to be used for setting up an augmented surveillance grid.

REFERENCES & BIBLIOGRAPHY

1. White Paper on FOPEN Radar for UGS Applications by Sergio Gallone.
2. EW & Radar Engineering Handbook – Naval Air Warfare Centre, California.
3. Book Titled 'Foliage Penetration Radar' – Mark E Davis.
4. Article in Science & Technology Magazine – Radar Counters Camouflage.
5. Brochure – Elbit Sys (IAI) – FPR 10.
6. Book Titled 'Foliage Penetration Radar: History & Developed Technology' – Louis Surgent, Army Land Warfare Lab, Maryland.
7. White Paper on Radiowave Propagation Through Vegetation' by Mir Ghoraishi & Jun Ichi Takada.
8. Trans Nav Article - Surveillance Unattended Foliage Penetrating Radar for Border Control and Homeland Protection by F. Amato, A. Farina, M. Fiorini & S. Gallone, Selex ES –A Finmeccanica Company, Rome, Italy.

CERTIFICATE

The paper is author's individual scholastic articulation. The author certifies that the article is original in content, unpublished and it has not been submitted for publication / web upload elsewhere and that the facts and figures quoted are duly referenced, as needed and are believed to be correct. The paper does not necessarily represent the views of the CENJOWS.