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SIDE LOOKING DRONE RADAR FOR BURIED VEHICLES IN THE FORESTALL ENVIRONMENT

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Abstract: *Surveillance of artillery and blinded vehicle by the drones is usually based on the optical devices mounted on the drone platforms. This method has the problem to detect arms buried in the forestall environments especially if the vehicles are masked by different methods. In this paper simple side locking radar mounted at the drone bottom side is proposed. This radar is intended to detect artillery and blinded vehicle masked in the forestall environment. One dimensional antenna array is proposed to avoid aerodynamic disturbance. Antenna operates at UHF frequency and can penetrate through the woods and similar environments. Because target dimensions are in order of few meters radar operates in optical zone. Eight radiating elements with 10W output power should be enough to cover the distances in the range of 1.5km to 15km. Length of the antenna is 2m and height 30cm. Radial resolution is 1.5m. Angular precision is obtained by the low frequency narrowband filter. It depends from the radial distance but average value of tents of meter could be assumed as the initial value.*

Keywords: *Linear array, SAR imaging, UHF radar.*

1. INTRODUCTION

Typical method for artillery system masking assumed protection in optical spectrum. For that reason drones guiding the own artillery cannot detect the target and cannot sent to own center precise coordinates of the enemy troops. Artillery or armored vehicles are covered with masking reds or are buried in the woods. Solution for detecting masked arms should be found in radar device application.

Detection and tracking are the functions most-commonly associated with radar. Increasingly, however, radars are being used to generate two-dimensional images of an area. Such images can be analyzed for intelligence and surveillance purposes, for elevation/topology mapping, or for analysis of earth resources issues such as mapping, land use, ice cover analysis, deforestation monitoring, and so forth. While radar images have not achieved the resolution of optical images, the very low attenuation of electromagnetic waves at microwave frequencies gives radar important advantage of seeing through clouds, fog, precipitation and vegetation very well. Consequently, imaging radars generate useful imagery when optical instruments cannot be used at all [1].

Especially in recent years, along with the SAR (synthetic aperture radar) imaging technology has been great focused, many experts and scholars have shifted their research focus to achieve the high-quality imaging both in efficiency and resolution. These studies can be departed to three parts: the SAR imaging technology, real-beam scanning imaging technology and mono-pulse imaging technology. These research results have greatly improved the imaging quality, but for e.g. the missile borne detector, these algorithms seem too complex. On the other hand, the limited space in the novel optional burst height proximity fuze require the complexity of signal processing algorithm and imaging strategy, therefore, in [2] authors propose a novel monopulse forward-looking high-resolution imaging algorithm based on adaptive iteration. In this type of radar, the antenna is mounted in the nose of the missile, which limits its dimensions, and thus the gain. Concept is proven experimentally by drones.

In our previous work [3] linear array antenna mounted along the missile body is presented. Linear array consists of patch type radiating elements. The array has maximum gain at the plane orthogonal to the missile, so it is optimal for side looking.

In this paper, we were looking for a radar concept that would be airborne, have a high-gain antenna (for good resolution and range) and a simple processing method (for high efficiency). The choice fell on a side looking radar that would be mounted below drone body.

2. RADAR CHARACTERISTICS

Radar has to operate at low frequency enabling electromagnetic propagation through the natural protections including the short propagation through the ground. Taking into account dimensions of the artillery or armored vehicle radar can operate in optical zone (RCS independent of wavelength) at the UHF frequencies (between 0.7m and 0.3m). Penetration through the ground should be better if the radar operates in the resonant zone i.e. VHF band (wavelength between 1.5m and 0.7m). Application of VHF band radar requires higher Tx power for the same antenna dimension as it is applied at the UHF radar. Dimension of the radar antenna has to be in accordance with drone capability and aerodynamic requirement. As an example, UHF radar (with (VHF intermediate signals) is proposed. Radar antenna should be realized as the linear array of 16 horizontal dipoles. Horizontal dipoles are selected because artillery tubes are mainly positioned in the horizontal direction and polarization losses are minimized. Brewster angle enables that lot of energy reflected from the ground shouldn't be reflected to the radar increasing the signal clutter.

In order to determine enemy artillery position, position of drones and drones trajectory should be known with high precision. For that reason pitch, roll, yaw (especially) component of the drone flight should be known for the calculation process.

Example of the useful radar characteristics are presented below:

- Operating frequency UHF band 675MHz
- Wavelength 45cm
- Linear array - number of elements 16
- Antenna gain 20dB
- RCS > 1m^2
- Pt> 100W
- NF<2dB
- Antenna length 5m
- Antenna height 0.3m
- Beam width in azimuth 6°.
- Beam width in elevation 50°.
- Pulse duration 50µs (blind zone 7.5 km)
- PRI – 200µs (unambiguous range 30km).
- PRF 5kHz
- S/N 20dB
- Effective bandwidth 100Hz
- Coherent integration time 40ms.
- Drone speed 200m/s
- Drone flight height 7km

According previous data radar range is:

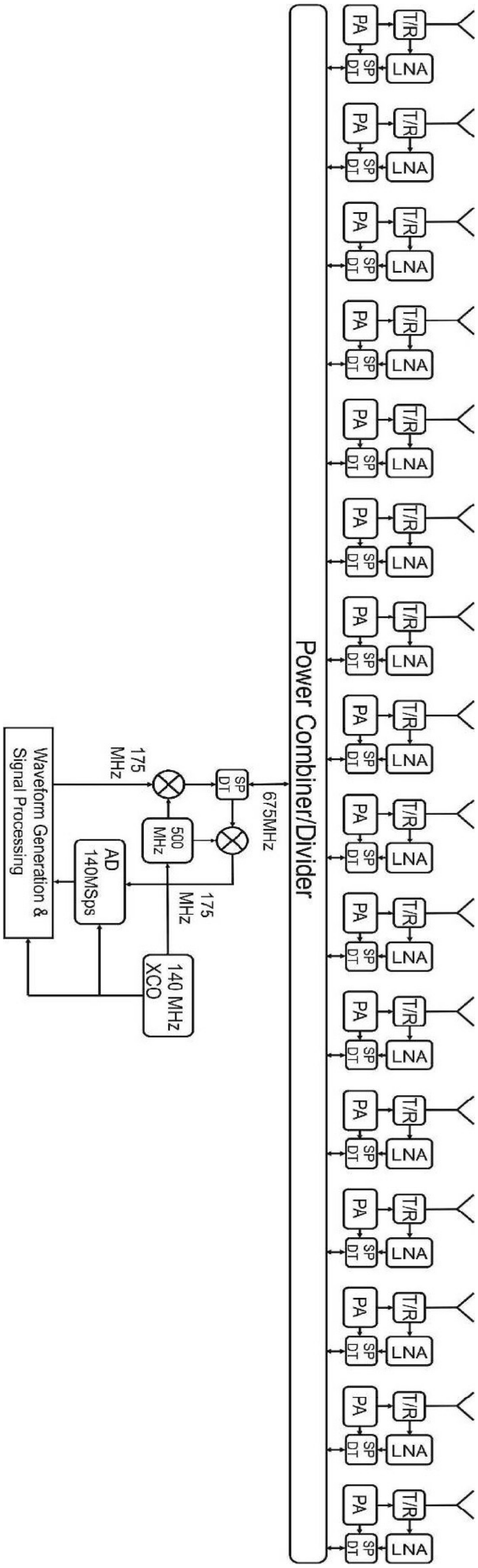

Figure 1. Radar block diagram

$$R = \sqrt[4]{\frac{P_t G^2 \lambda^2 \sigma}{(4\pi)^3 \left(\frac{S}{N}\right) kTF}} = \sqrt[4]{10^{18}} = 30 \text{ km} \qquad (1)$$

Distance resolution should be 3m. It means that signal bandwidth is 50MHz. Chip period is 20ns. During the time of 50μs sequence has 2500chips i.e. processing gain is 34dB.

Block schematic of the radar is presented at the Fig. 1. Radar is based on active linear array consists of dipole type radiating elements and T/R modules. The T/R module includes power amplifier, LNA stage, circulator and T/R switch. Because antenna operates at low frequencies, price of transmitter/receiver is low and availability of component is not limited.

Waveform generator and signal processing unit can be realized as in [4].

3. PERFORMANCE ASSESSMENT

Spot illuminated by the radar depends of the distance between radar and target. As a rough estimation width of the illuminated spot is 10% of the distance. For example, width of the spot at 30km is 3km. Unfortunately, operating frequency has to be low and Doppler frequency of the reflected object at the edge of the spot is low. Target selection based on the Doppler shift can reduce the spot width to half (1.5km at 30km distance). Even that obtained S/N is 20dB precision of the target position should be limited to 150m.

There are two options for better precision in target location process. First is to apply synthetic radar principle to determine target position [5] and second is to determine target position by two drones flying over orthogonal (or nearly orthogonal) trajectory as it is illustrated on Fig. 2.

Synthetic radar technique is based on coherent integration of the energy reflected from the target. Delay of the reflection from the particular target is equalized for different radar position. In order to equalize these delays radar need significant processing power. Powerful signal processor could be situated at the drone or reflected signal could be transferred to ground for further processing.

In the case of two drone application information about target position is obtained almost immediately. Both drones measure radial distance with high radial resolution and precision. Target position is obtained in the cross section of the axial resolution lines.

Taking into account flying speed of 200m/s and integration time of 40ms drone will pass 8m illuminating target. In that case resolution cell of 3×8m could be assumed as the maximum resolution area. Time of 40ms could be assumed as the Doppler resolution cell of 25Hz. Maximum Doppler frequency is generated by the targets at the edge of radar spot. In the case that beam width is 6° maximum radial velocity of target should be:

$$v_{rad\max} = v_{drone} \sin\left(3^\circ\right) = 0.05 v_{drone} = \frac{10\text{m}}{\text{s}} \qquad (2)$$

Then, the maximal Doppler frequency is:

$$f_{d\max} = \frac{2v}{c} f_c = 45\text{Hz} \quad f_{dmax} = \frac{2v}{c} f_c = 45Hz \qquad (3)$$

In the case that drone velocity is halved (100m/s) Doppler shifts should be negligible. In the case of VHF antenna with the similar dimension beam width should be 4 times wider and radial velocity of the target should be four times higher. As the central frequency is four times lower Doppler shifts should be the similar as it is in the UHF band. For Doppler shifting elimination, only two times longer antenna or two times lower drone speed could be useful.

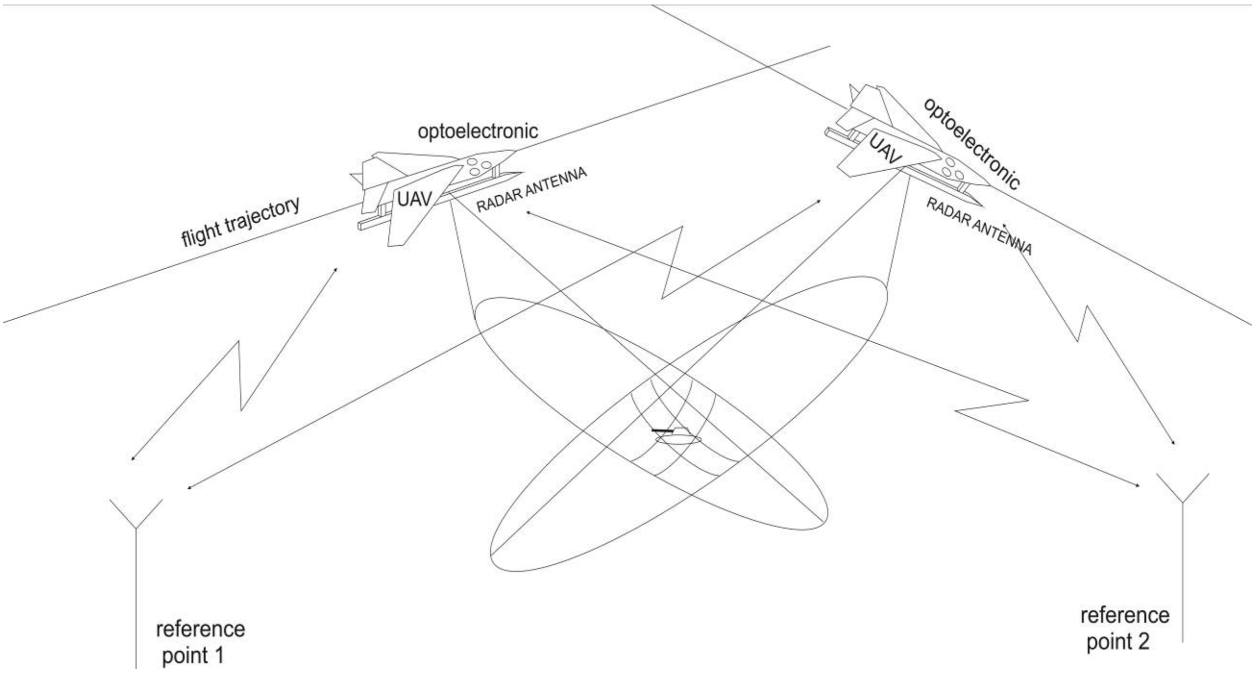

Figure 2. Double drone observation concept

In the first phase of the signal processing response from different range gates are obtained. Targets with Doppler frequency should be reject what means that simple integration of the received signal should during the 40ms should be performed. In this way reflected signals from all range gates (7500) are obtained.

Next step in the signal processing should be SAR integration process. All response corresponding to one resolution cell should be integrated during the illumination time period. This process could be numerically too complex for simple on board computer and should be performed at the ground.

Numerically complicated process could be replaced by double drone observation.

4. CONCLUSION

Concept of side looking radar for buried vehicles in the forestall environment is presented. Antenna operates at UHF frequency and can penetrate through the woods and similar environments. The initial calculation shows that even when the S/N of 20dB is obtained, the accuracy of the target position is limited to 150m, which is not enough to guide one's own artillery.

Two options for better precision (of order 3×8m) in target location process are considered. First of them is to apply synthetic radar principle to determine target position and the second one is to determine target position by two drones flying over orthogonal (or nearly orthogonal) trajectory.

The first method is computationally complex and requires a powerful processor, situated either on the drone's board or on the ground, but with fast communication link to drone in addition. The second method is computationally much simpler, but requires two drones.

References

[1] RICHARDS M., *Fundamentals of Radar Signal Processing*, McGraw-Hill, New York, 2005.

[2] CHENG C., ZHOU X.D., ZHU-LIN M.G., at all, *Research on monopulse forward-looking high-resolution imaging algorithm based on adaptive iteration*, Defence Technology, 16(1), (2020), 158-171.

[3] GOLUBIČIĆ Z., SIMIĆ S., ZEJAK A., *Multi-beam receiving antenna at the missile lateral structure*, Proc. of 6th International Conference OTEH 2014, Belgrade, Serbia, October, 2014.

[4] GOLUBIČIĆ Z., SIMIĆ S., MARIĆ S., ZRNIĆ B., PAVKOVIĆ B., *Simple Radar System for Drone Surveillance and Acquisition*, Proc. of 10th International Conference OTEH 2022, Belgrade, Serbia, October, 2022. (*submitted*)

[5] ANTONIJEVIĆ G., SIMIĆ S., BUJAKOVIĆ D., *Improving the azimuth resolution of strip-map SAR image using Adaptive Weighted Norm Extrapolation*, 25th Telecommunication Forum (TELFOR), Belgrade, Serbia, November, 2017