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SIMPLE RADAR SYSTEM FOR DRONE SURVEILLANCE AND ACQUISITION

ZORAN GOLUBIČIĆ
Institute RT-RK Computer based systems, Novi Sad, Serbia, golubicic.zoran@gmail.com

SLOBODAN SIMIĆ
Military Academy, Belgrade, Serbia, slobodan.simic@va.mod.gov.rs

SVETISLAV MARIĆ
University of California, San Diego, USA, smaric@ucsd.edu

BOJAN ZRNIĆ
Military Academy, Belgrade, Serbia, zrnic_bojan@yahoo.com

BOGDAN PAVKOVIĆ
Institute RT-RK Computer based systems, Novi Sad, Serbia, bogdan.pavkovic@rt-rk.com

Abstract: *This paper is dedicated to drone surveillance system taking into account main drone characteristics – low RCS and limited vehicle speed. As a nominal values maximum drone speed of 100m/s (360km/h) and RCS of $10^{-3}m^2$ are assumed. Radar system has to fulfill two main requirements. Drone has to be detected at the distance longer that it is the drone missile operating range (about 20km max) and price of the radar component should be significantly lower than it is the price of antiradar missile. As a solution quasi bi static system is proposed. Low RCS target is detected by the long energy integrated during the relatively long time (0.25s). Beam width is optimized according the drone dynamic. System with 10 beam width is obtained as the optimal solution. Required power for continuous wave radar operation was 5W. Maximum distance for drone detection was 30km. System operate at Ku band require parabolic antenna of 1.5m. Systems operating at other bands need proportionally larger or smaller antennas. In order to surveillance certain solid angle sector few Tx antenna are necessary. Exact number is discussed in the paper.*

Keywords: *quasi bistatic radar, continuous wave radar, COTS technology, Doppler processing*

1. INTRODUCTION

Massive application of drones in the recent wars generates mythology about drone efficiency in the combat environment. Drones were applied successfully against non-prepared and non-protected artillery and armored vehicle. Massive drone attacks had the surprising effect typical for the new system application. Systems that were used for defense were classic anti-aircraft system. These systems were used more or less successfully. These systems are many times more expensive than attacking drones. Surveillance and acquisition system of these systems are not optimized for anti-drone operation. Target of this design is to design the cheap systems capable to detect drones at the distances where usual attacking arm (missile) is useless. Price of the radar system is significantly below the one missile carried by drone. Main performances of the drones are low RCS and low flying speed. Second performance offers possibility to radar to accumulate lot of reflected energy in the long time. Reflected energy should be accumulated during the target illumination and pulse Doppler radar is not adequate for this application. For that reason quasi-bi-static radar should be applied.

2. TYPICAL SCENARIO

Typical parameters relevant for drone detection are as follows:

- Drone RCS $10^{-3}m^2$ (it is assumed that RCS is constant over the frequency of 7.5GHz i.e. 4cm wavelength)
- Drone maximum speed 100m/s (360km/h)
- Radar radial resolution 50m
- Radar frequency between 7.5GHz and 18GHz
- Radar wavelength 1.5cm to 4cm
- Tx power 5W
- Antenna gain 42dB to 46dB
- Parabolic dish antenna diameter 1.3m to 3m
- Beam width 1°
- S/N 14dB
- Equivalent bandwidth 4Hz

According the previous data maximum radar range should be (3cm wavelength is used as example but other wavelength, using the proper antenna, shall give the same results):

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

According the previous calculation during the time of 1s radar can surveillance angular space of 2°×2°. During 100s drone can pass maximum 10km radial distance. For 100s radar can cover 20°×20° angular spaces.

These data can be used as the starting point for the particular design.

For example, in the case that 50W amplifier is available (typical for communication purpose) bandwidth cold be amplified to 40Hz. It means that solid angle of 60°×60° could be illuminated in 100s.

3. RADAR ARCHITECTURE

Radar is based on two antennas (Tx and Rx) separated few tents of meters and central unit. In this way simultaneous signal transmission and reception are enabled. Rx antenna integrates LNA stage. LNA stage is connected to central unit via coaxial cable. Tx antenna is connected with the central unit via waveguides providing low losses between central unit and transmission antenna. Inside the central unit power amplifier, synthesizer with frequency converters, waveform generator and signal sampler are accommodated. Signal processing should be performed off line by the classic host computer. General schematic is presented at the Fig. 1.

Because Tx antenna is the most susceptible to anti-radar missile attack it is practically impossible to protect this antenna from the destroying by anti-radar missile. But the price of this antenna (parabolic dish with rotating mechanism) is many times below anti-radar missile and technology required for these antenna fabrications is not high and it is available for almost all countries.

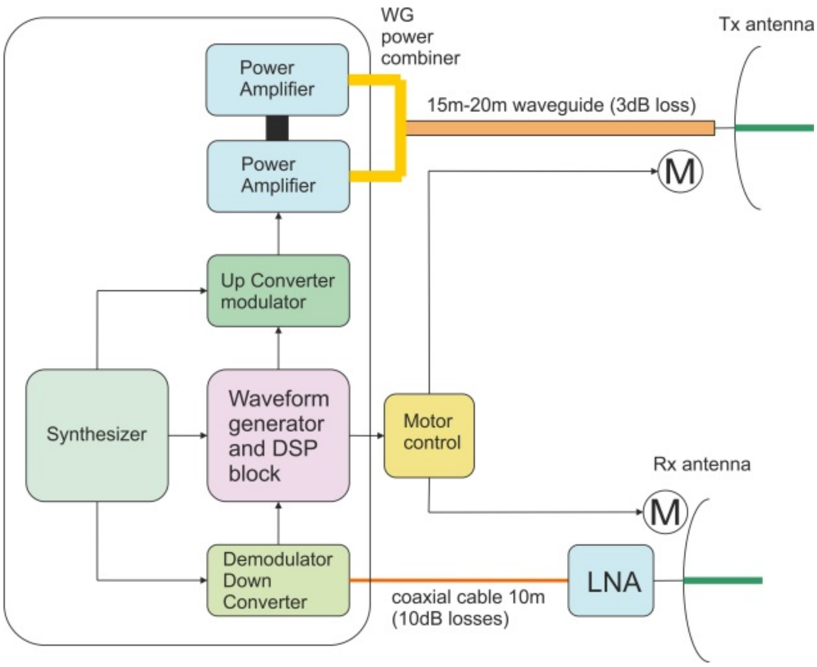

Figure 1. Radar block diagram

Key radar component is the power amplifier. Availability of this component is the problematic for all radar manufacturers, except for the some of them situated in the most powerful countries. For that reason, in the case of unavailability, power amplifiers based on the powerful RF electronic tubes or semiconductors usually used in other fields of application (industrial or scientific equipment etc.) could be applied. As an example, tubes or semiconductors applicable in different microwave transmitteror plasma heating devices could be useful. Separation of power amplifier position from the Tx antenna significantly increase the probability of amplifier survivability. Sometimes two parallel amplifierscould be combined in order to compensate waveguide losses. Taking into account problems with amplifier availability this unit can be accommodated in the armored box (in order to survive missile attack).

In the cases when attack of anti-radar missile is not expected (or amplifier unit is available by the domestic production) power amplifier could be joint to Tx antenna and flexible coaxial cable could be applied for the connection between amplifier and the rest of the radar.

Because Rx antenna doesn’t radiate electromagnetic power radar central unit could be associated to the Rx antenna. This antenna is protected from the anti-radar missile but it could be recognized by the optical equipment. It means that this antenna should be the protected by the classical masking methods.

3.1. Synthesizer with up/down converters

Basic component of the synthesizer presents commercially available crystal oscillator operating with the frequency about 100MHz (with low phase noise).

Frequency of this signal could be multiplied between 8 and 20 times by the commercially available UHF transistors or Schottky diodes used in usual mobile communication equipment. Obtained signal could be multiplied 9 times (×3 and ×3) by the low power transistors (usually applied in LNB blocks for satellite signal receivers) or by Schottky diodes used in the LNB mixers. Similar component could be applied for the receiver low noise amplifier and mixer. All these components are in the mass production with low price. Low frequency mixer/modulator could be realized by the Schottky diode applied for the LO signal synthesizer design. Purpose of these architectures is to enable signal processing part independent of radar operating frequencies.

Important components in the synthesizers design and fabrication are filters. Frequency plan assume application of commercially available SAW filters at 1070MHz (SSR) and 70MHz is usual IF frequency for telecommunication equipment. Frequency distances between components in the multipliers, modulators and demodulators are enough that microstrip filters (with IQ modulators and demodulators) can select desired frequencies.

Example of the block diagram of the synthesizer with up/down converter (for X-band radar) is presented at the Fig. 2. Presented synthesizer is only example. Depending of the available power amplifier frequency plan could be adopted but cheap and commercially available component should be applied.

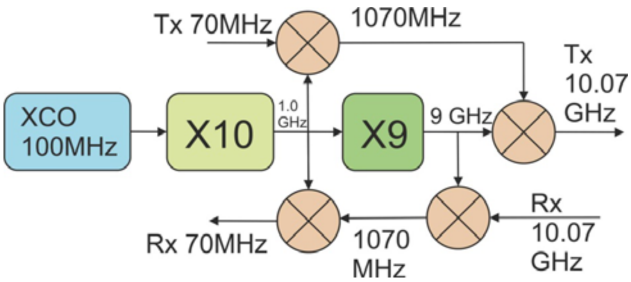

Figure 2. Block diagram of the synthesizer

3.2. Waveform generation and signal sampling

Because maximum drone speed is 100m/s and signal integration time is 250ms drone can pass 25m during the integration time. In order to enable high probability to detection distance resolution should be 50m. Signal bandwidth should be 3MHz. In order to fulfill under sampling condition with sufficient guard band for signal filtering RF bandwidth should be extended to 5.64MHz and IF frequency to 70.5MHz. Sampling frequency should be 11.28MHz (available by the cheap AD converter).

BPSK Tx signal should be generated by modulated periodic bit stream of 141Mbit/s (01010101…). This stream is modulated by 3Mbit/s (47bits 010101... are included in the one information bit). Generation of Tx signal is possible by simple FPGA circuit or standard microcontroller.

Sampling rate of 11.28MSPS could be performed by the AD converters with serial outputs. Even that signal is coded with 16bits output stream has bit rate below 200Mbit/s. This velocity is compatible with standard microprocessor or FPGA devices.

Block schematic of the generation and sampling signal is presented at the Fig. 3.

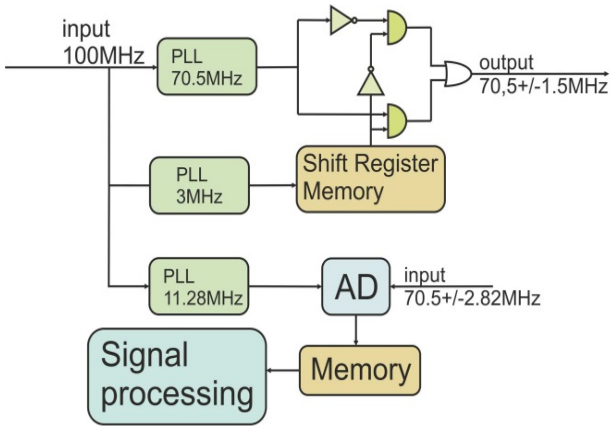

Figure 3. Frequency plan for signal generation and sampling

3.3. Signal processing

First step in the signal processing part is IQ signal forming. Pair and impair samples are separated as I and Q samples. Impair samples in I and Q streams are multiplied by -1 and two components of base band signal are obtained [1]. Fir filter is used to reject all image bandwidth in the under sampling process. Signal is correlated with the long sequence. Because integration time is long, bank of the matched filters should be applied. FFT processor is optional.

Figure 4. Off-line processing

4. POINTING CALIBRATION

One of the main problems in the bi static radar operation is the antenna pointing synchronization. This problem could be resolved using own drone transmitting the signal from the far field distance (250m or more). Both antennas Tx and Rx has to have small monopulse receivers for initial position calibration. These antennas could be used for passive drone detection in the case that drone radiate some signals. Pointing system can operate at the different frequency than radar.

In the case that spillover problem could be solved at the small distance between Tx and Rx antenna both of them could be positioned at the one rotating platform. Availability of low noise amplifier is not problematic i.e. destroying of both (Tx and Rx) antenna is not critical damage.

To prove concept, an experiment was done with available hardware. Experimental setup is shown on Fig. 5.

Figure 5. Experimental setup

Figure 6. Corner reflector used for calibration

Two ground surveillance radars PR-15 [2], and one corner reflector [3], shown on Fig. 6, were used. The radar on the left in Fig. 5, with parabolic antenna were illuminating the target, while the radar on the right, with flat printed antenna, was passive and used as receiver. Considering that PR-15 radar

- has antenna with gain of 30 dB which is quite smaller than that one proposed in Section 2,
- cannot work continuously without hardware adaptation, so it can give maximum average power of 600 mW which is quite smaller than that one proposed in Section 2,

experiment was done at smaller distance (5 km) than requested in Section 2 (30 km) and with the target quite bigger than drone. The distance between Tx and Rx antenna was small, but their positions and orientations were fixed, so it was possible to place them in such a way as to avoid the spillover problem.

The results are shown on Fig. 7. Methodology was the same as in [4]. The time – Doppler signal representation is shown. The complex signal with duration of 13 seconds measured by receiving PR-15 radar (top), spectrogram of this signal (centre) and its projections on Doppler axis (left) are shown.

Pedestrian was walking away of radar. After 10 seconds, he stopped and started to wave with a corner reflector. The signal originates from the range cell at distance of 4.9 km of the radar. Bi-phase coded radar pulse with duration of 19.2 μs is applied in transmitter. Golay complementary sequences lengths of 64 are used for coding.

As there is noticeable variation in the amplitude of its real (blue) and imaginary (red) parts we can conclude that signal is above the noise. However, that variation is slow, indicating that it is caused by strong ground clutter. It is better shown in spectrogram, in the middle at zero Doppler. We can see one non-stationary component corresponding to moving person and his activities with the corner reflector in the range cell.

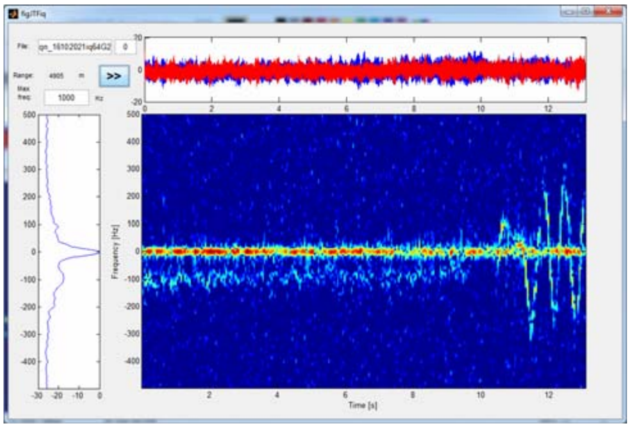

Figure 7. Time – Doppler signal representation

5. CONCLUSION

Concept of drone surveillance radar system taking into account main drone characteristics – low RCS and limited vehicle speed is presented. Calculation shows that small drone with RCS of $10^{-3}m^2$ can be detected at maximum distance at 30km, with continuous wave radar power of 5W, with parabolic antenna of 1.5m at Ku band. Experimental verification of the concept at smaller distance of 5 km was done with two ground surveillance radars PR-15 and one corner reflector.

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