FMICW TECNIQUES APPLIED TO A Ka BAND SAR ON BOARD UAV

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Abstract- This paper describes the waveform analysis for an experimental long-range (10 Km) high-resolution (1x1 m2) Synthetic Aperture Radar (SAR) sensor in the millimetre wave band on board UAV. Motivated by the need to minimize the transmitted power and the volume filled by the sensor, it is proposed the use of a FMICW (Frequency Modulated Interrupted Continuous Wave) radar type. It also is provided a comparison between two simulations; one with a unique antenna configuration (FMICW) and another one with two antennas (FMCW).

Key Words: FMCW, FMICW, SAR, UAV, range resolution, azimuth resolution.

1. INTRODUCTION

This paper presents some results of a study developed for analyze the viability of a SAR sensor (Synthetic Aperture Radar) with a weight, volume and consumption that allows take on board unmanned aerial vehicles (UAVs) with very low payloads. Therefore, very demanding requirements have been established accordingly both the need of being on board aerial platforms with the exposed limitations, and the required high provisions by terms of resolution and quality at images.

To be precise, the design prototype will work at millimetre band (at 35 GHz). This band presents the following advantages for realising High Resolution Radar (HRR) Systems opposite lower frequencies or optics:

- Possibility of night and day use, with steam and adverse meteorological conditions (short range with rain). This aspect offers the possibility of observation through obstacles like clouds, steam, etc.
- Reduction of antennas and equipment sizes, enabling take on board smaller dimension platforms.
- High resolution and precision, since/because great bandwidth signals can be used.
- Mature and affordable technology.

All these characteristics convert this technology in the perfect candidate to the proposed application [1]. A resolution capability of 1 meter range and azimuth resolution involves the use of great bandwidth signals and synthetic aperture antennas. The main advantage achieved with high resolution image radars is the increase of the available information at the system to detect, localize and identify the presence of all types of objectives, because the multiple reflectors which forms the real targets can be divided at the reception process.

The Frequency Modulated Continuous Wave (FMCW) form is an excellent alternative to obtain high resolution in surveillance radars [2][3]. Its main characteristics are the following:

- Much less power to same range is required, so it allows the use of solid state technology, with the extraordinary advantages that this involves (Low Probability of Interception (LPI) techniques).
- More easily signal processing.
- No minimum distance.
- Low probability of interception, limiting the coverage of Electronic War equipments for detecting their emissions.
- Low interference with other systems.

However, presents some inconvenient:

- The necessary isolation between the transmitter and the receiver in continuous operation at HF frequencies is very difficult to achieve.
- Signal levels decrease rapidly with distance exceeding the dynamic range due to the propagation losses.
- The volume filled by this pair of antennas, due to the required gain for achieving range and peak power fixed, is unavailable at small aerial platforms at which we look just for miniaturizing, as far as possible, the components size.
- The elimination of near clutter presents great difficulties.

A very interesting alternative to improve isolation problem is based on the use of a switch (T/R) between transmitter and receiver. The idea consists in switching the antenna several times per transmitted ramp reaching more than 60 dB of isolation between transmitter and receiver [4]. This technique is named Frequency Modulated Interrupted Continuous Wave (FMICW).

2. FREQUENCY MODULATED INTERRUPTED CONTINUOUS WAVE (FMICW)

Known as FMICW or IFMCW, this technique assumes the signal interruption in order to fulfill the good isolation requirement between transmitter and receiver. Generally, it is implemented with a transmission time fitted with go and return propagation delay, and another one of reception of the same value achieving a 50% duty circle.

With these conditions, a reduction of 3 dB in average transmission power is achieved, as well it improves the system performance against noise by means of increasing SNR in more than 3 dB designated for decrease of isolation losses [5].

Following figure (Fig.1) shows the principle of performance. The idea consists in using a square signal with a 50% duty circle for switching the antenna between the transmitter and receiver, so that transmitted signal has an aspect as shown in Fig. 1.d. In following figures, two illustrative examples show the dependency between the target detection and its distance to the sensor.

Based on the results, it can be noticed that radar detects better more far targets (Fig 1.e) because it receives its echo during more time and, so, compiles more information about this one. In the second case (Fig. 1.f), since the distance to the target is smaller, the propagation time is reduced and so the receiver echo signal is not collected, because the antenna is still transmitting. So it can be deduced that more far targets, more attenuated due to propagation losses, have more sensibility than more close ones.

This problem causes the appearance of a minimum range due to finite propagation time and to the need of knowing the target range to optimize the transmission time. Due to this fact, this must be optimized to the maximum range of interest (where SNR is lower), so that the sub-optimum zone is where the probability of target existence or target interest range is smaller. The most commonly choice of the chopping frequency consists in that the received signal of a target situated at maximum range has a delay equal to half period of commutation wave. By this way, the better choice for commutation frequency is:

$$f_c = \frac{c}{4R_{máx}} \tag{1}$$

The minimum range previously mentioned tends to cancel in some zones, for which its associated sensibility is cero. These are the so called blind zones and are determined by:

$$R_B = \frac{c}{2f_c}n \qquad n = 0,1,2,3... \tag{2}$$

Therefore, the distance interval under exploration must fit between two blind zones (2).

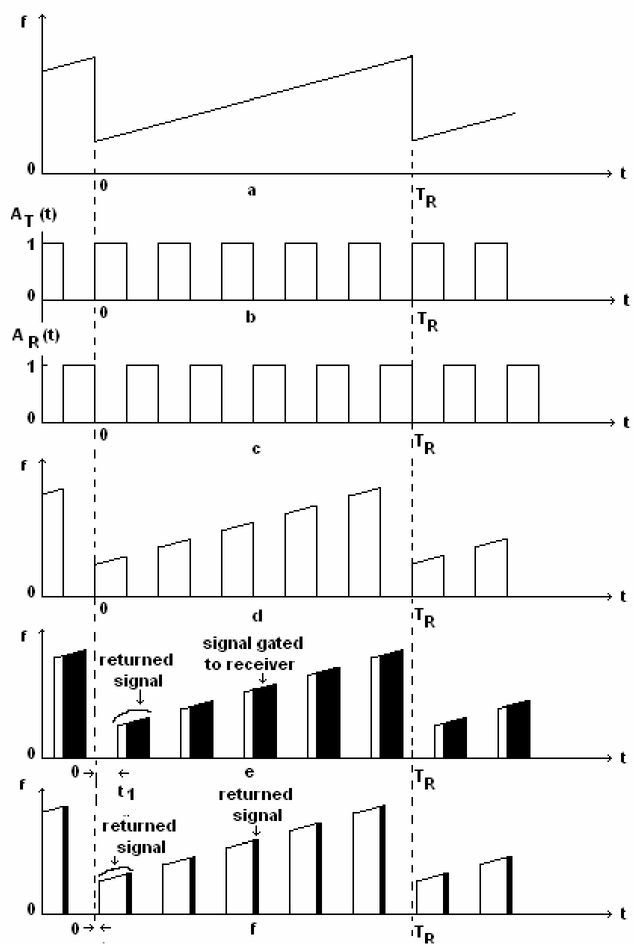

Fig. 1. FMICW technique: (a) Generated FMCW signal, (b) Transmitter gating sequence, (c)gating sequence (complement of transmit sequence), (d) FMICW signal using the gating sequence b, (e) FMICW signal echo from target with two way travel time of t_1 seconds, (f) FMICW signal echo from target with two way travel time of t_2 seconds [5].

3. DESIGN TOOL

To calculate the parameters for the two SAR systems wave forms to compare, it has been developed a design tool that follows the process line shown at Fig 2.

So, once chosen the system work frequency, the first step is determinate the PRF (pulse repetition frequency). At the beginning, it's obtained from an approximation in which the transmitted pulse length (T_x) is not consider (not defined at this moment), due to suppose it like a little contribution in relation with other factors of the PRF expression. Next, a first value of T_x is estimated from the obtained PRF. Later, the pulse repetition frequency is recalculated and, subsequently, the transmitted pulse length. This iterative calculus converges rapidly in one or two iterations.

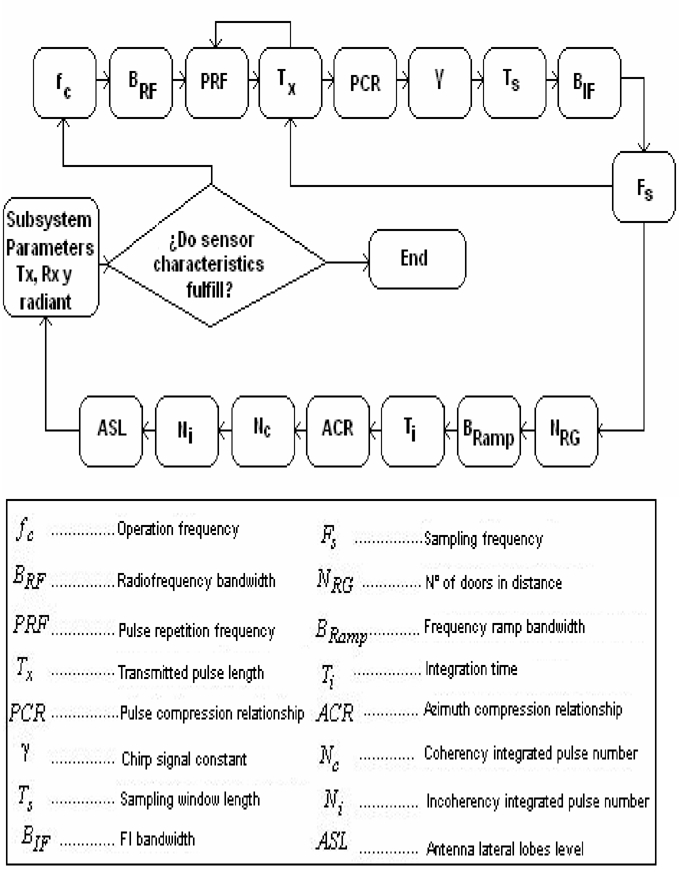

Fig. 2. Calculation Algorithm

Similar feedback cycles are used in the determination of other factors, like sampling frequency or intermediate frequency bandwidth, due to the dependency that some of them presents between themselves.

4. SIMULATIONS AND RESULTS

It is expected to design a SAR system in millimetre band at 35 GHz frequency that fulfils certain requirements imposed by the platform at which UAV will take on board.

Two simulations have been done, one with FMCW technique and another one with the technique commented during present paper, to check the suitableness of its application in these types of stages.

Initial characteristics imposed to sensor are collected in the following table:

Azimuth beam width	$\theta_{Az\text{-}3dB} \le$	*2º*
Elevation beam width	$\varphi_{El\text{-}3dB} \le$	*2º*
Gain at T_x (with losses)	$G_{TX0} \ge$	*38 dB*
Gain at R_x (with losses)	$G_{RX0} \ge$	*38 dB*
Maximum transmitted power	$P_{peak} \le$	*0,006 Kw*
Transmitted pulse length	$T_x <$	*300 µs*
Instantaneous bandwidth	$B_i <$	*1000 MHz*
Maximum antenna noise figure	*Fant <*	*8 dB*
Antenna TOI	$TOI_{ant} >$	*-39 dB*
TOI CE+RFC	*TOI CE+RFC >*	*-23 dB*

Table 1: Emission parameters of millimetre radar

The system geometry is defined by the following parameters:

Nominal flight height	*6000 m*
Nominal flight velocity	*200 Km/h*
Range Resolution	*1 m*
Azimuth Resolution	*1 m*
Maximum width of the strip under exploration	*2 Km*
Minimun range over ground	*12 m*
Maximun range over ground	*24 m*
Maximun squint angle	*45º*

Table 2: System Geometry

Given these premises, in the following lines it is shown the sensor designs for each of the selected techniques with the tool mentioned in the previous section.

4.1.FMCW

System design parameters obtained by means of using frequency modulated continuous wave signal (100% duty circle) for the sensor under study are shown in next table:

SYSTEM PARÁMETERS			
Parameter	***Units***	***Value***	***Comments***
F_c	*GHz*	*35*	
BRF	*MHz*	*226,402*	*For minimum "y"*
PRF	*Hz*	*4352*	
T_x	*µs*	*246,32*	
PCR		*55767*	
Γ	*MHz/µs*	*0,9191*	
T_S	*µs*	*270,79*	*For the strip*
B_{FI}	*MHz*	*22,49*	
F_S	*MHz*	*27*	
P_{peak}	*Kw*	*0,002*	
$P_{average}$	*w*	*2,14*	
DC	*%*	*100*	
G_{Tx}	*dB*	*45*	
G_{Rx}	*dB*	*45*	
N_{RG}		*29245*	
B_{Ramp}	*MHz*	*248,88*	
T_i	*µs*	*88,8576588*	

Table 3: System parameters with FMCW

BEHAVIOUR AGAINST NOISE			
(dB)	*Squint Angle (º)*		
	0	*20*	*45*
CNR (y_{max}, s_0 = -25 dBm^2/m^2)	*5,92*	*5,65*	*4,41*
SNR (y_{max}, s = 10 m^2)	*43,72*	*43,45*	*42,21*
SCNR (y_{max}, s_0 = -25 dBm^2/m^2, s_0 = 10 m^2)	*36,81*	*36,75*	*36,46*
NESZ (y_{max})	*-30,92*	*-39,65*	*-29,41*

Table 4: Behaviour against noise with FMCW

SYSTEM RESOLUTION			
Range resolution	$\delta_r =$	*0,92*	*m*
Azimuth resolution	$\delta_a =$	*0,16*	*m*

Table 5: System Resolution with FMCW

It can be checked in the tables that, to achieve a transmitted power around 2 or 3 waits, two antennas with 45 dB are necessary, which supposes diameters of around 25-28 inches that, multiplied by two, involves an exorbitant and unviable volume in the project under study.

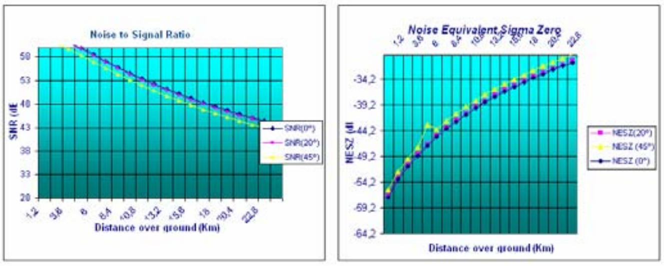

Figure 1: SNR and NESZ Graphics with FMCW

4.2.FMICW

The following parameters of a FMCW design are obtained using a 50% duty circle switching the antenna by equal intervals between receiver and transmitter:

Parameter	*Units*	*Value*	*Comments*
SYSTEM PARÁMETERS			
F_c	*GHz*	*35*	
BRF	*MHz*	*226,402*	*For minimum "y"*
PRF	*Hz*	*4352*	
T_x	*µs*	*124,16*	
PCR		*28110*	
γ	*MHz/µs*	*1,8235*	
T_S	*µs*	*148,63*	*For the strip*
B_{FI}	*MHz*	*44,63*	
F_S	*MHz*	*54*	
P_{peak}	*Kw*	*0,003*	
$P_{average}$	*w*	*1,62*	
DC	*%*	*54,0344*	
G_{antena}	*dB*	*45*	
N_{RG}		*16052*	
B_{Ramp}	*MHz*	*271,03*	
T_i	*µs*	*88,8576588*	

Table 6: System parameters with FMICW

It must be emphasised the fact that, due to the antenna reuse by the transmitter and receiver, system power balance can be improved up to 3 dB (in case of 50% duty circle) [6][7].

As it can be noticed in the previous table, reducing duty circle to half, it can be achieved an average power reduction (P_{av}) of the same measure, as well as to dispense with one of the antennas and, therefore, of the volume occupied by it. Apart from these parameters, also variations in other ones exist: pulse transmitted length, pulse compression ratio (PCR) and process window length (T_S) are reduced to half; chirp signal slope (γ), signal bandwidth at FI mixer output (B_{FI}) and A/D converter sampling frequency (F_S) are duplicated. The number of distance doors (N_{RG}) sees its value decreased in slightly over half and FM ramp bandwidth increases his value softly respect FMCW.

BEHAVIOUR AGAINST NOISE			
(dB)	*Squint Angle (º)*		
	0	*20*	*45*
CNR (y_{max}, s_0 = -25 dBm^2/m^2)	6,51	6,24	5,01
SNR (y_{max}, s = 10 m^2)	44,31	44,04	42,8
SCNR (y_{max}, s_0 = -25 dBm^2/m^2, s_0 = 10 m^2)	36,92	36,87	36,6
NESZ (y_{max})	-31,51	-31,24	-30,01

Table 7: Behaviour against noise with FMICW

Comparing two technique behaviours against noise we can check that, eliminating one of the two antennas, signal to noise ratio is improved, so it is required a decrease in noise existing levels.

SYSTEM RESOLUTION			
Range resolution	$\delta_r =$	*0,92*	*m*
Azimuth resolution	$\delta_a =$	*0,16*	*m*

Table 8: System Resolution with FMICW

System resolution remains constant due to the fact that no dependent parameter has been modified.

As a consequence of suffered changes in previous parameters, FMICW graphics show an improved performance too.

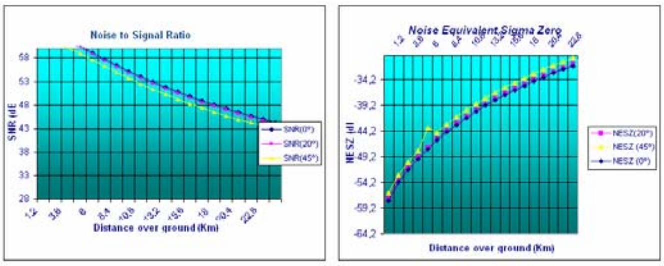

Figure 2: SNR and NESZ graphics with FMICW

Finally, it must be checked the suitability of the application of FMICW technique with regard to generated blind ranges and the switching frequency choice.

As previously it has been established, blind zones are set with the expression (2). Taking chopping frequency as the one which fulfils the condition of the target echo placed at maximum range with a delay of half switching wave period, we obtain:

$$f_c = \frac{c}{4R_{máx}} = \frac{c}{4*24Km} = 3125 \text{ Hz} \quad (3)$$

So system blind ranges are determined by

$$R_B = n * 48000 \ (m), \quad n = 0,1,2,3... \quad (4)$$

Distances that are out of the problem field given the maximum range required, so we can conclude that this last design fits perfectly to our necessities.

4.3. RAIN EFFECT

Previous simulations have been realized assuming a standard atmospheric attenuation with clear time.

Rain effect has been considered too, concluding that range is reduced to 5 Km. for 5 mm/h intensities, which implicates that sensor could work with flight height around 2 Km.

5. CONCLUSIONS

In this paper the application of FMICW technique has been analyzed at high resolution radar to achieve the demanded powers and capacities to SAR sensors to be on board small platforms such as UAV.

Results permit evaluate and compare FMCW and FMICW techniques in the project environment and conditions to demonstrate that, although experience would lead us thinking initially in choosing FMCW, the introduced modify of interrupting transmitted signal and sharing the antenna between transmitter and receiver, provides a more feasible solution under the imposed requirements.

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