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DSSS Based Radar Altimeter

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Abstract:The basic functions of a radar altimeter is to provide accurate altitude measurements above the Earth surface with a high degree of accuracy and integrity during the approach, landing, and climb phases of aircraft operation. In this paper a design of Direct Sequence Ranging System useful for the development of spread spectrum based radar altimeter is proposed. Radar altimeter measures altitude more directly, using the time taken for a radio signal to reflect from the surface back to space vehicle. In Spread Spectrum technique the spectrum of the modulated signal is spread to cover a wider range of frequency spectrum. It offers features like resistance to jamming, transparency to unfriendly receiver, high resolution ranging etc.

Basic building blocks of a direct sequence spread spectrum based delay measurement system are simulated using Matlab. From the measured delay, the range is estimated and the accuracy/resolution of the ranging system is analysed from the results.

Keywords: Spread spectrum, Direct Sequence Spread Spectrum, PN sequence, Gold sequence, Radar altimeter

I. INTRODUCTION

An altimeter is an instrument used to measure the altitude of a space vehicle above landing surface. Radar altimeter [1] measures altitude more directly, using the time taken for a radio signal to reflect from the surface back to space vehicle. Conventional radar altimeters use FM-CW ranging technique. FMCW radar [1][2] system is susceptible to interference from other radio devices as they are continuously transmitting across a frequency band. This is due to the larger range of frequencies encountered and due to the lower peak power, resulting in the returned signal being overwhelmed by other emissions. Also due to the lower power and continuous transmissions of FMCW systems, they may be more easily jammed by electronic warfare systems. As these radar systems continuously transmit, they are easily detected by electronic warfare systems. In order to overcome the disadvantages of FM-CW ranging a direct sequence ranging system [3] is proposed which can be used for spread spectrum based radar altimeter. Spread spectrum techniques [4] were initially developed by the military to send data and messages without being affected by jamming (intentional interference) or detection by the enemy. In addition it is used in satellite communications, cellular telephony, Global Positioning System (GPS) etc.

Spread-spectrum techniques are methods by which a signal (e.g. an electrical, electromagnetic, or acoustic signal) generated with a particular bandwidth is deliberately spread in the frequency domain, resulting in a signal with a wider bandwidth. In the proposed system, the spread spectrum modulated signal is BPSK modulated and transmitted and on reception, Costas loop is used for demodulation and, the carrier and the data signals are recovered. The delay of recovered data signal can be estimated by correlating it with the transmitted signal and from the delay the range can be calculated.

II. PROPOSED SYSTEM

The proposed system consists of two sections: transmitting section and receiving section. In the transmitting side, the data sequence is spread using a PN sequence and the spread sequence is BPSK modulated and transmitted. In the receiving side the received signal is demodulated using a Costas loop and the carrier and data signals are recovered. And in order to estimate the delay the transmitted signal and the recovered signal are correlated. Figure 1 illustrates the different stages of Direct Sequence Ranging System.

In the figure, g(t) represents the spread signal which is BPSK modulated and transmitted as s(t),a Direct Sequence signal with power Ps.

$$s(t) = \sqrt{2P_s}g(t)cos\omega_0 t \quad (1)$$

The signal is reflected from the intended target and received T1+T2 seconds later as r(t).

$$r(t) = \alpha s(t - T_1 - T_2) = \alpha\sqrt{2P_s}g(t - T_1 - T_2)\cos(\omega_0 t + \theta) \quad (2)$$

where α represents the signal attenuation and θ is a random phase caused by the time delay [3]. The carrier $\sqrt{2}cos\omega_0(t - T_1 - T_2)$ and the data sequence are

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determined using a squaring circuit or a Costas loop. Here a Costas loop is used. From the recovered signal and the transmitted signal the delay is estimated using correlation. Hence range can be calculated.

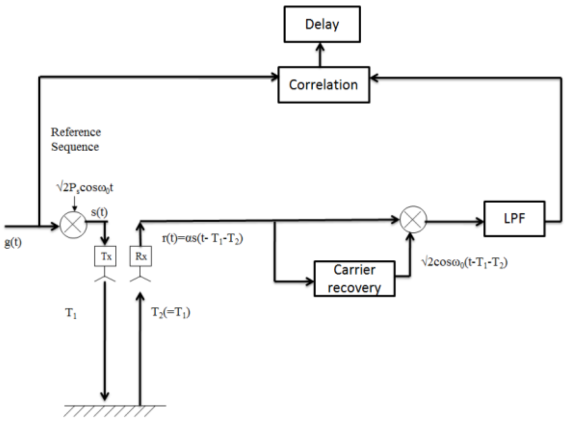

Fig.1. Ranging Using DS Spread Spectrum

III. TRANSMITTER SECTION

In the transmitter, by using spread spectrum technique the desired sequence to be transmitted is spread and the obtained sequence of desired length is BPSK modulated. BPSK modulation is the most robust of all the PSK's, since it takes the highest level of noise or distortion to make the demodulator reach an incorrect decision.

A. Generation of PN Sequence

An essential component in spread spectrum communication system is pseudo-random or pseudo-noise (PN) sequence which is used at the transmitter to generate the wide band transmitted signal and at the receiver to recover the narrowband message. The most widely known binary PN sequences are the maximum-length shift register sequence or m-sequence. A maximum length shift register has length $L=2^N-1$ bits and is generated by a N-stage shift register with linear feedback as shown in figure2.The sequence is periodic with period N. Each period of the sequencecontains2^{N-1} onesand$2^{N-1}-1$ zeros [5].

The hardware used to generate such a PN sequence is shown in the figure2.It consists of a shift register and a parity generator. The shift register is made of D flip-flops arranged in a way that each data input except D_0 is the Q output of the preceding flip-flop. The input to D_0 is the output of parity generator and the outputs of flip-flops are connected to parity generator. In the figure 2 the inputs to parity generator are shown in dashed line to indicate not all Q outputs need to be connected to parity generator. The character of the generated PN sequence depends on the number of flip-flops employed and on the selection of which flip-flop outputs are connected to the parity generator [3]. A register of N flip-flops has 2^Nstates from $Q_0Q_1Q_2\ldots Q_{N-1}$=000...0to111...1. Actually the maximum sequence length is 2^N-1, since the state 000...0 must be excluded as if arrived; it will remain in that state permanently.

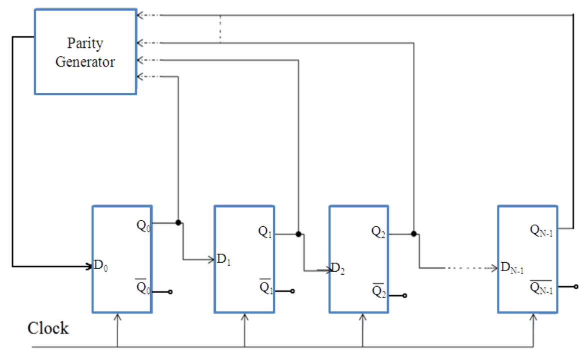

Fig.1. Maximum Length PN Sequence Generator

It is clear that the hardware in the figure cannot create truly random sequence, since it is a deterministic structure. Each time the generator arrives at some particular state, the subsequent sequences of states will always be the same i.e. the sequences will repeat and will be periodic. Hence the generated PN sequences will have correlation properties. However the sequence length before repetition is usually extremely long and is truly random, i.e. there is no correlation at all between the value of a particular bit and the value of any other bits. The correlation properties of the pseudorandom noise (PN) sequence are very important in determining the overall performance of a Direct Sequence Spread Spectrum (DSSS) system [3].

A PN code sequence must possess adequate randomness properties (such as high variance and low autocorrelation), have long periods and be difficult to reconstruct from short segments. The randomness property includes equal probability of a one or a zero in a binary coded sequence. Long periods prior to repetition are important since the auto-correlation function determines the spectrum spreading. Long periods also affect the amount of cross interference with other users sharing the same frequency spectrum in Code Division Multiple Access (CDMA) situations. Reconstruction difficulty due to long segments reduces the probability that false locks occur in the synchronization of the receiver to the transmitter.

In anti-jamming applications of PN spread spectrum signals, the period of the sequence must be large in order to prevent the jammer from learning the feedback connections by observing only 2N-1chips from the PN sequence. This vulnerability of the PN sequence is due to the linearity property of the generator.To reduce this vulnerability to a jammer, the output sequences from several stages of the shift register or the outputs from several distinct m sequences are combined in a non-linear way to produce a

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non-linear sequence that is considerably more difficult for the jammer to learn. Further reduction in vulnerability is achieved by frequently changing the feedback connections and/or the number of stages in the shift registers according to some prearranged plan formulated between the transmitter and the intended receiver [5].

The periodic cross correlation function between any pair of m sequences of the same period can have relatively large peaks.PN sequences with better periodic cross correlation properties than m sequences have been given by Gold and Kasami. The proposed system is designed using a Gold sequence of 2047 bits.
Gold sequences [5] [6] are defined using a specified pair of sequences u and v, of period L= 2^N-1, called a preferred pair. Two m-sequences of length L with a periodic cross correlation function that takes on the possible values −1,−t(N),t(N)−2 are called preferred sequences, where

$$t(N) = 2^{(N+1)/2} + 1 \text{(odd N)} \quad (3)$$
$$= 2^{(N+2)/2} + 1 \text{(even N)} \quad (4)$$

From a pair of preferred sequences u and v, a set of sequences of length L can be constructed by taking the modulo-2 sum (XOR) of u with the L cyclically shifted versions of v or vice versa. L new periodic sequences with period L = $2^N - 1$ are obtained. The original sequences u and v can be included to have a total of L + 2 sequences. The L + 2 sequences constructed in this manner are called Gold Sequences.

$$G(u, v) = u, v, u \oplus v, u \oplus T v, u \oplus T^2 v, u \oplus T^{N-1} v \quad (5)$$

where T represents the operator that shifts vectors cyclically to the left by one place, and ⊕ represents addition modulo 2.

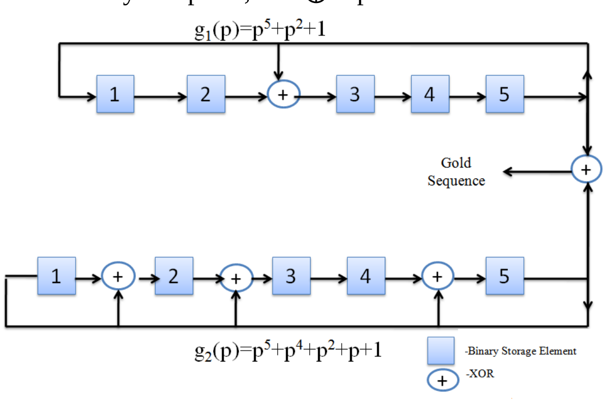

Fig.3. Gold Sequence Generator of Length 31

The shift registers for generating the two m sequences and the corresponding Gold sequences for N = 5 are shown in figure 3. In this case, there are 33 different sequences corresponding to the 33 relative phases of the two m sequences. Of these, 31 sequences are non-maximal length sequences. With the exception of the sequences u and v, the set of Gold sequences is not comprised of maximum length shift register sequences of length L. Hence their autocorrelation functions are not two valued [5]. In the proposed system a gold sequence of 2047 bits, generated by 11-bit Gold sequence generator is used.

B. Spread Spectrum Modulation

Spread-spectrum is a means of transmission in which the signal occupies a bandwidth in excess of the minimum necessary to send the information; the band spread is accomplished by means of a code which is independent of the data [11]. This is a technique in which a telecommunication signal is transmitted on a bandwidth considerably larger than the frequency content of the original information. Spread spectrum generally makes use of a sequential noise-like signal structure to spread the normally narrowband information signal over a relatively wideband (radio band) of frequencies.

Spread spectrum modulation is done either to resist enemy efforts to jam the communications (anti-jam), or to hide the fact that communication is even taking place, called low probability of intercept (LPI). These techniques are used for a variety of reasons, including the establishment of secure communications, increasing resistance to natural interference, noise and jamming, to prevent detection, and to limit power flux density (e.g. in satellite downlinks). Therefore spread spectrum modulated signal can be defined as a signal which occupies a bandwidth that is much larger than the minimum bandwidth (1/2T) necessary to transmit a data sequence [3]. The wider bandwidth is obtained by spreading the spectrum of data sequence by means of a pseudo-noise code. In the proposed method, the data sequence is bit XOR-ed with the generated PN sequence to form the spread spectrum signal.

C. BPSK Modulation

In binary phase shift keying (BPSK) the transmitted signal is a sinusoid of fixed amplitude. It has one fixed phase when the data is at one level and when the data is at other level the phase is different by 180^o. The modulating signal is a binary sequence and is multiplied with a sinusoidal carrier, thereby obtaining the BPSK modulated signal. The BPSK modulation is preferred when small amount of data is transmitted and offers acceptable bit error rate while transmitting signals of relatively low energy [7].

Binary Phase Shift Keying, in terms of noise immunity per unit bandwidth is one of the most efficient binary data modulation techniques. It has high spectrum efficiency, good spectral characteristics, and strong anti-interference performance, faster transfer rates etc [8]. So the spread sequence is BPSK modulated and this Direct Sequence Spread Spectrum modulated signal is transmitted.

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IV. RECEIVER SECTION

A number of tasks have to be performed in the receiver to reconstruct the symbol stream. Because the data modulate the carrier, the symbol stream must be demodulated by a convenient procedure. Demodulation is of two types, Coherent or synchronous demodulation and non-coherent demodulation. Coherent demodulation is more efficient, especially if noise has been added to the signal when it propagates across the data link. When Coherent detection has to be applied, the receiver must know the phase of the carrier exactly i.e. the receiver must reconstruct a replica of the carrier.

In BPSK modulation, data signal and carrier are multiplied; hence their spectrum will contain lines at the sum frequency $f_s + f_d$ and at the difference frequency $f_s - f_d$, where f_s and f_d are the carrier and data frequency respectively. Normally the data signal is an arbitrary sequence of logical ones and zeros [9].

There are two well-known coherent demodulation techniques for BPSK: a squaring loop and a Costas loop. In the proposed system Costas loop is used because it is more tolerant of frequency shift and is capable of operation over a wider bandwidth than a squaring loop [10]. Also the Costas loops working frequency is lower than the square loops working frequency and don't need the squarer or frequency divider [11]. The double frequency components are eliminated by the low pass filter following the multiplications, in the case of a Costas loop. It offers an inherent ability to correct the phase and frequency of the recovered carrier. While the squaring loop is a feed forward technique, the Costas loop relies on feedback concepts related to the PLL. It performs both phase coherent suppressed carrier reconstruction and synchronous data within the loop. The basic Costas loop is shown in figure 4.

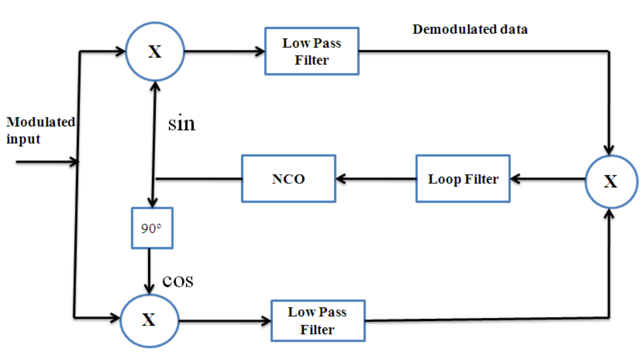

Fig.4. Costas Loop

A. Costas Loop

It consists of three multipliers called mixers, two low pass filters, a loop filter, a numerically controlled oscillator. The input signal is sent to two multipliers of the upper called in-phase branch and the lower called quadrature branch. In-phase branch multiply input by NCOs output and quadrature branch multiply input by NCOs output, after a

90^o phase shift. The multiplier joining the two arm acts as a phase detector. The function of phase detector is to extract the phase error signal between the input signal to the loop and the local carrier signal generated by NCO. Loop filter adjusts and smooth the phase error. Then adjusted phase error is used to control NCO in order to generate the corresponding frequency carrier. When the carrier frequency and the phase generated by the NCO are coincident with the transmitter carrier frequency and phase, the demodulated signal can be extracted from the in-phase branch.

B. Correlation

Correlation is a measure of similarity between two quantities. Correlation between two waveforms can be understood by multiplying the waveforms together at each instant in time and adding up all the products. If the waveforms are identical, every product is positive and the resulting sum is large. If however, the two are dissimilar, then some of the products would be positive and some would be negative, so the final sum would be smaller. Correlation is of two type auto-correlation and cross-correlation. Auto-correlation is a graph of the similarity (or correlation) between a waveform and itself, as a function of the time shift. The random noise is not similar to itself with any amount of time shift, so its auto-correlation has only a single spike at the point of zero time shift. Pseudo-random noise, however, repeats itself periodically, so when the time shift equals a multiple of the period, the auto-correlation repeats. Thus the auto-correlation of any periodic waveform is periodic and has the same period as the waveform itself. The same technique used by the auto-correlation, could be used to measure the similarity between two non-identical waveforms. This is called the cross correlation function. If the same signal is present in both waveforms, it will be reinforced in the cross correlation function, while any uncorrelated noise will be reduced [12]. In the proposed system both auto correlation and cross correlation functions are used in order to estimate the delay between transmitted and received signal.

C. Delay and Range Estimation

In the proposed system, the delay can be estimated from the results of correlation of transmitted and the received signal. The transmitted and the received sequences are correlated with the reference sequence. The reference sequence used is a portion of the transmitted sequence. The correlation of reference sequence and the transmitted sequence is like auto correlation and the correlation of reference sequence and the received sequence is like cross correlation. From the output of correlation, the difference in the position of peaks is found and this difference gives the delay between the transmitted and received signals. From the delay, the range

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can be estimated by using the formula $\frac{1}{2}cD$, where c is the velocity of light (3×10^8 m/s) and D represents the delay in time.

V. SIMULATION RESULTS AND DISCUSSION

In the proposed system, an input binary sequence of 50% duty cycle is XOR-ed with a 2047 bits (11-bit Sequence Generator) Gold sequence to obtain the chipped data. A portion of the generated sequence (chipped data) is shown in the figure 5. The obtained chipped data is then BPSK modulated for transmission. At the receiver side, a Costas loop is used to recover the carrier signal and the demodulated signal. The output from the NCO for the I-arm is a sine wave and for Q- arm is a cosine wave i.e., it is 90^o phase shifted. When the carrier loop is in phase lock and that the sine functions from NCO is in-phase with the incoming carrier signal, this results in a sine squared product at the I-output, which produces maximum amplitude for the output of I-arm multiplier. The cosine function from NCO is 90^o out of phase with the incoming carrier. This results in a $cosine \times sine$ product at the Q output, which produces minimum amplitude (noise only).

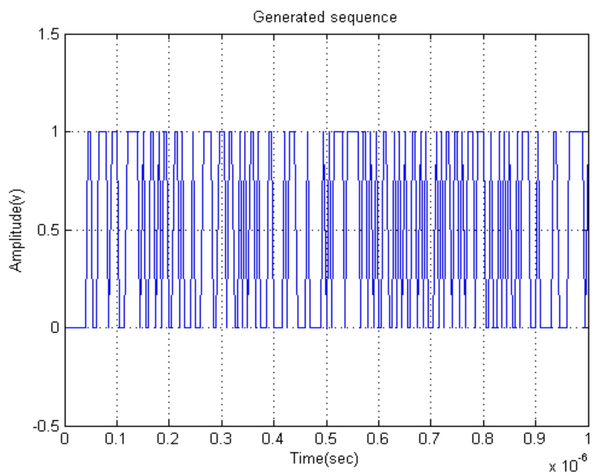

Fig.5. Generated Sequence (Chipped Data)

For this reason, output of I-arm multiplier will be near its maximum (and will flip 180^o each time the data bit changes sign), and output of Q-arm multiplier will be near its minimum (and will also flip 180o each time the data bit changes sign) [13]. The figure 6 shows a portion of the outputs of I-arm and Q-arm multipliers.

The input to the I-arm multiplier from the NCO, for which the loop is in phase lock, is the required carrier signal. By over plotting NCO output for the I-arm and the carrier signal used this can be understood, a portion of which is shown in figure 7. The outputs of I-arm and Q-arm multipliers are given as input to the low pass filters. The output of the I-arm low pass filter is the demodulated data. Since there is a 180o phase ambiguity with a Costas PLL, the detected data bit stream may be normal or inverted.

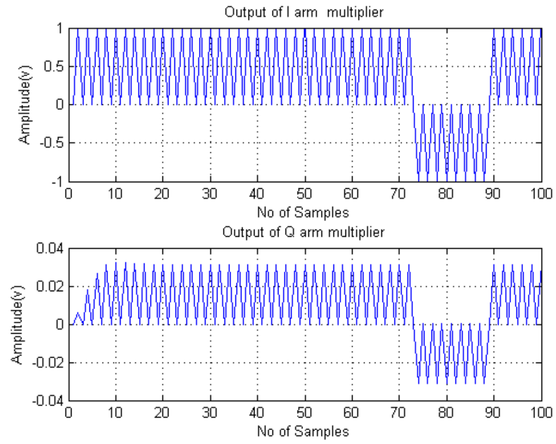

Fig.6. Outputs of I-arm and Q-arm multiplier

This ambiguity is resolved during the frame synchronization process by comparing the known preamble at the beginning of each subframe both ways (normal and inverted) with the bit stream. If a match is found with the preamble pattern inverted, the bit stream is inverted and the subframe synchronization is confirmed by parity checks. Otherwise, the bit stream is normal. Once the phase ambiguity is resolved, it remains resolved until the PLL loses phase lock or slips cycles. If this happens, the ambiguity must be resolved again [13].

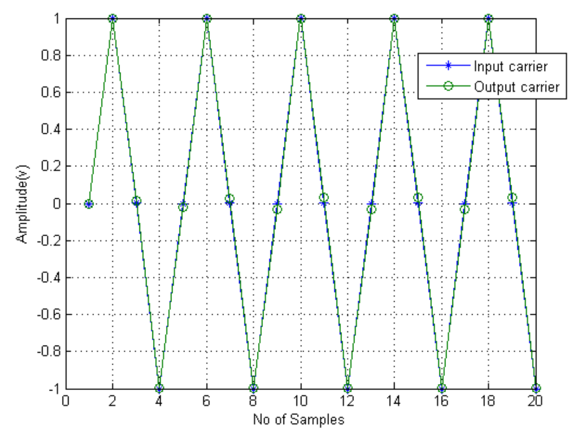

Fig.7. Comparison of Carriers

The outputs of low pass filters are given to a third multiplier, which is a phase detector. Phase detector extracts the phase error signal between the input signal of the loop and the local carrier signal. Loop filter adjust and smooth the phase error. The adjusted phase error controls NCO in order to generate the corresponding frequency carrier. This continues until the carrier frequency and the phase generated by the

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NCO coincides with the transmitter carrier frequency and phase [7]. The figure 8 shows the output of phase detector and loop filter.

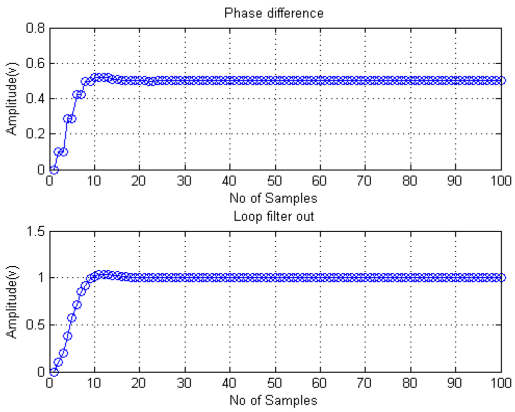

Fig.8. Outputs of Phase Detector and Loop Filter

In order to ensure that the demodulated data obtained from the I-arm is the transmitted data; both are over plotted, a portion of which is shown in figure 9. From the figure, it can be seen that the output of I-arm low pass filter 'I arm-filter' and the transmitted data 'data-delayed' are the same with a dc offset of 0.5v in the I-arm output.

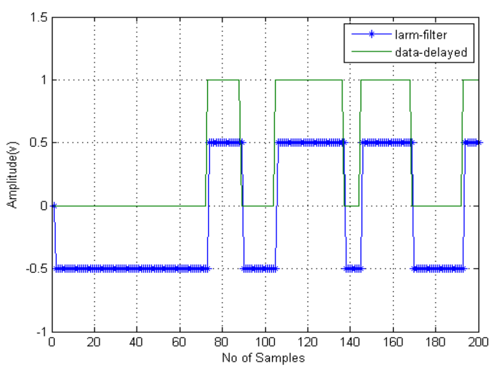

Fig.9. Comparison of Data Sequences

After obtaining the demodulated data, the next step is correlation. The transmitted sequence and the demodulated sequence are correlated with the reference sequence. Here the reference sequence used is a portion of the transmitted sequence. The figure 10 shows the results of auto correlation of transmitted sequence and the cross correlation of the recovered sequence from the Costas loop. It can be seen that there is a shift in the position of peaks, when the outputs of correlation are compared. The difference of the position of peaks gives the delay in time. The proposed system is designed with a sampling frequency of 200 MHz and carrier frequency of 50 MHz So time taken to transmit one sample is 5 ns. Consider the case, where the number of samples delayed is 50. The delay obtained by taking the difference of peaks is 0.25µs i.e.250 ns. As the time taken by 1 sample is 5 ns, 50 samples take 250 ns. Hence the estimated delay is correct. From this delay, the equivalent altitude that can be measured is given by.

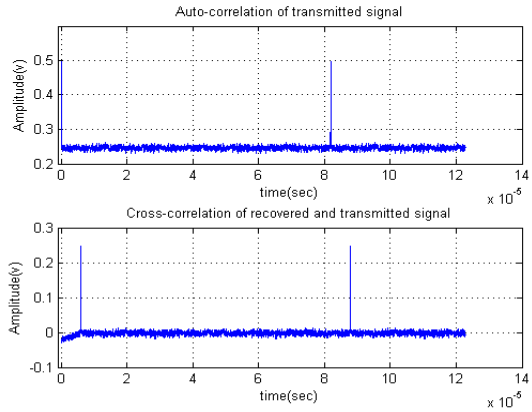

Fig.10. Output of Correlation

$$Equivalent\ Altitude\ (R) = \frac{1}{2} cD \qquad (6)$$
$$= \frac{1}{2} * (3 \times 10^8) * (250 \times 10^{-9})$$
$$= 37.5\ m$$

The table shows the equivalent altitudes for different delays. For a Gold sequence (11-bit shift register) of length 2047 bits maximum altitude range is 1535.3 m.

TABLE I
DELAY AND EQUIVALENT ALTITUDE

No of symbols delayed	Delay (s)	Equivalent Altitude (m)
10	0.05	7.5
20	0.1	15.0
50	0.25	37.5
100	0.5	75.0

VI. CONCLUSION

Conceptual design of a direct sequence ranging system for spread spectrum based radar altimeter was carried out. The basic function of a radio altimeter is to provide accurate height measurements above the Earth surface with a high degree of accuracy and integrity during the approach, landing, and climb phases of aircraft operation. Spread Spectrum technique used in the proposed system offers advantages like anti-jamming, anti-interference, low probability of intercept, high resolution ranging etc.
A Costas loop is used to demodulate the carrier and transmitted data. The range (equivalent altitude) can be estimated

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by cross correlating the transmitted and demodulated data. By using a sampling frequency of 200 MHz for demodulated signal, resolution of 0.75 m can be achieved for the system. By using a Gold sequence (11-bit shift register) of length 2047 bits maximum altitude range is 1535.3m and, by using a PN sequence (12-bit shift register) of length 4095 bits maximum altitude range of 3071.3m can be achieved. In order to enhance the altitude range of the system maximum length and Gold sequences of higher bits can be used.

Future works include simulation of Doppler shifts, measurement of bandwidth of the carrier recovery loop, simulation of fading effects, effect of Additive White Gaussian Noise (AWGN) and the signal to noise ratio threshold, the hardware implementation and its working under different conditions.

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