SFCW Based Proximty Sensor for Collison Avoidance With High Resolution

Fouziya C, Vikas Kumar, T.Venkatmuni, Kalyani Murthy
Central D&E (RFC)
Bharat Electronics Limited
Bangalore, Karnataka, India
fouziyac@bel.co.in, vikas_kumar@bel.co.in,

Abstract*—Dumper Collision Avoidance System has been developed as a safety system for Dumpers operating in Open-Cast mines. One of the requirements of the system is to provide information about presence of the objects in short range with high resolution. To fulfill these requirements, proximity sensors which works on radar principle has been used. Stepped frequency compression techniques are used to generate radar waveforms for high range resolution. Concept is simulated and bench level results presented in this paper.

Index items: SFCW, IFFT,STC

I. Introduction

Vehicle-to-vehicle collisions remain one of the highest causes of accidents on surface mine sites worldwide. Numerous studies have determined that the root cause of many mine site collisions is poor visibility or blind spots associated with large mining equipment. There are now a number of commercially available systems using a wide range of sensing technologies that provide a more efficient means to alert equipment operators of potential collisions and the proximity of at-risk objects. Radar based proximity sensors in the GHz spectrum provide excellent distance measurement performance in applications where high accuracy, repeatability and reliability are needed. Due to the non-contact nature of the measurement system, and due to the nature of the microwave, SFW radar operating in the GHz range also exhibit excellent resistance to dust, steam, heat, etc. And their ability to determine range over very short or fixed distances, SFW based systems have also been in transportation applications, including automotive collision avoidance radars. The SFCW radar technique offers substantial benefits over impulse radar systems. The main advantage of the stepped-frequency technique is that it is relatively easy with current technologies to efficiently sample SFCW signals with low speed A to-D converters due to very low instantaneous bandwidth. Also, due to the transmission of long duration waveforms, a high average transmitted power is much easier to obtain than for short-pulse and impulse waveforms. Another advantage of stepped-frequency radar is its ability to skip over frequencies, which makes it jammer resistant.

The stepped frequency waveform is an interpulse pulse compression method in which the carrier frequency of successive pulses is varied by a fixed frequency step. Wide bandwidth is indirectly achieved over several pulses instead of within a single pulse as in conventional pulse compression signals. The effective waveform bandwidth is the product of the number of coherently integrated pulses and the frequency step size. The returns of these pulses at different carrier frequencies constitute the frequency Spectrum of the target reflectivity and are coherently integrated by the IFFT(Inverse Fast Fourier Transform) to yield the high resolution range profile (HRR profile).

II. Background principle of SFCW radar.

The principle of operation of SFCW radar is therefore very similar to the FMCW radar, and by closer examination, we observe that the SFCW waveform can be viewed as a discrete version of an FMCW waveform. Wide bandwidth is indirectly achieved over several pulses instead of within a single pulse as in conventional pulse compression signals as shown in fig1. The effective waveform bandwidth is the product of the number of coherently integrated pulses and the frequency step size. In fact, the digitized baseband signals from both systems contain exactly the same information about the target echo since the SFCW baseband signal is simply a discrete version of the beat signal of corresponding FMCW radar. The key advantage of the stepped frequency method compared to other pulse compression techniques is that the range resolution is increased while maintaining a narrow instantaneous bandwidth. As a result, the analog to digital conversion requirements are less stringent. The SFCW is shown in Fig 1.

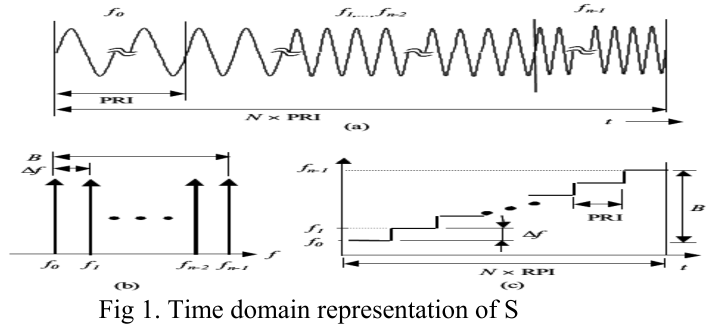

Fig 1. Time domain representation of S

Stepped frequency continuous wave radar determines distance information from the phase shift in a target reflected signal. It determines the distance to targets by constructing a synthesis range profile in the spatial time domain using the IFFT as shown as

$$Tx=A1.\cos(2*\pi*fn*t+□n) \quad (1)$$

Where Tx is Transmitter signal for nth signal and φn is relative phase

$$Rx=A2.\cos(2*\pi*fn*(t-\tau)+\varphi n) \quad (2)$$

Where Rx is target signal returned after the round trip time τ as shown as

$$\tau=2R/C \quad (3)$$

Where R denotes range of target

III. Conceptual Design of SFCW Based Proximity Sensor for Collision Avoidance with High Resolution

A simple block diagram of Proximity Sensor working with SF-CW radar principle is shown in Fig 2.

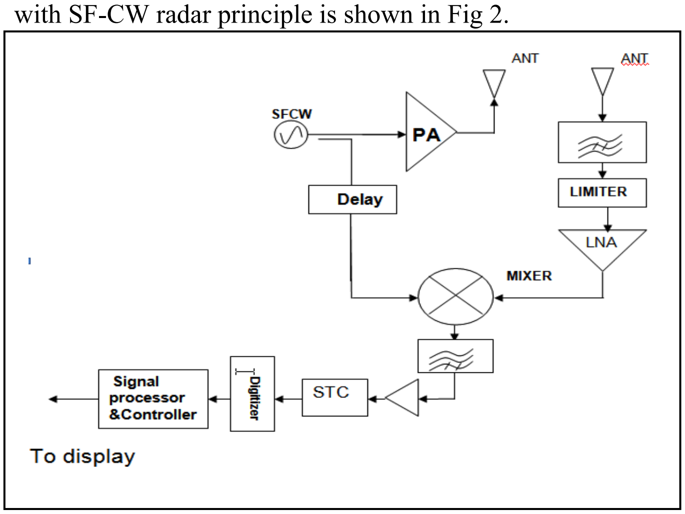

Fig 2. Functional block diagram of Proximity Sensor

Synthesized SFCW signal from source is amplified and fed to patch antenna through a directional coupler. The directional coupler allows a major portion of the SFCW signals through while a portion of the signal is made available as the reference. Reference signal is sent to the local oscillator (LO) port of the mixer. Two separate patch antennas are used to transmit the SFCW signal and to receive the reflected signal from the target. The received signal from the antenna is sent to the RF port of the mixer through the band pass filter, limiter and low noise amplifier (LNA). This is mixed with reference signal is present on the local oscillator (LO) port of the mixer. Output of mixer can be modeled as product of received signal with the reference signal followed by Low pass filter as shown as

$$XI(t)=An*\cos(□n(t)) \quad (4)$$

$$XQ(t)=An*\sin(□n(t)) \quad (5)$$

Phase of mixer output □n (t) is shown as

$$\omega n*\tau=2*\pi*fn*\tau \qquad (\tau=2R/C) \quad (6)$$

FM ranging is based on measurement of phase deviation of the target echoes. The range is converted into a frequency shift fd, thus it is possible to resolve and measure the range to the target by resolving the frequency shift in the phase equation. The range to the target can be obtained by rewriting R in terms of fs as shown as

$$R=fd*(c*\tau/2\Delta f) \quad (7)$$

Δf = change in frequency from signal to signal

Digital signal processing tools such as inverse Fourier Transform (IDFT) and pulse integration can used for range estimation.

IV. PLL Based SFCW Simulations

The complete hardware setup of a low cost C-band SFCW radar using commercial off-the-shelf electronic components is shown in Fig 3. A linear FM sweep of 500MHz bandwidth with a very low phase noise output is generated using phase locked loop (PLL) evaluation board which consists of X band VCO.

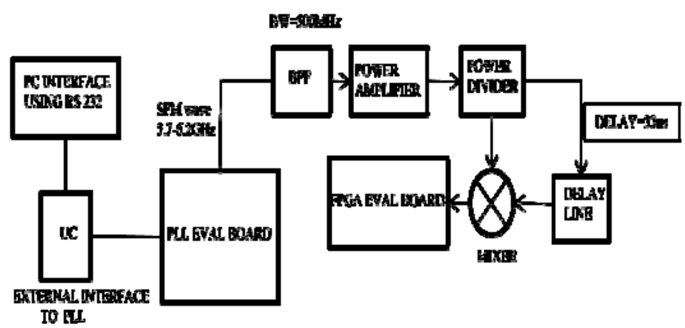

Fig 3. Hardware setup for Proximity Sensor

The PLL is programmed using a microcontroller which also controls the start/stop time and the bandwidth for directly generating a UWB SFM sweep at C band of 5.7 to 6.2GHz using VCO.The signal limited using a band pass filter of 500MHz bandwidth and is time delayed using transmission line based delay line. The delayed signal is mixed with its non-delayed counterpart in the mixer. Output of mixer is given to ADC and FPGA for evaluating range information from beat frequency of mixer after signal conditioning.

The Hardware parameters for SFCW Synthesizer is

Parameters	Specifications
Frequency	5.7-6.2GHz
Bandwidth	500MHz
Total sweep time	55.66us

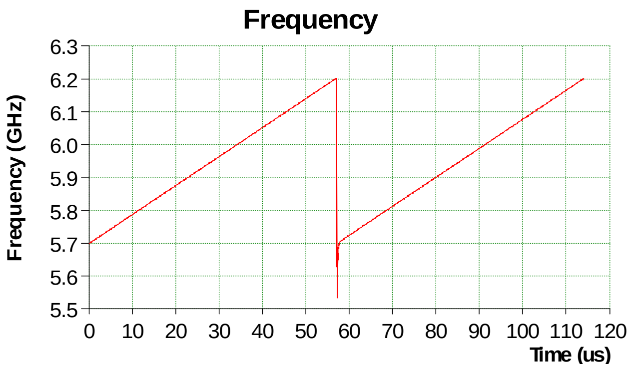

Fig 4 Simulation results of Sim PLL

In order to understand the behavior of the proposed hardware, a design simulation of the various subsystem blocks is done in Matlab .The transmitted and received spectrum has been shown in Fig 5.

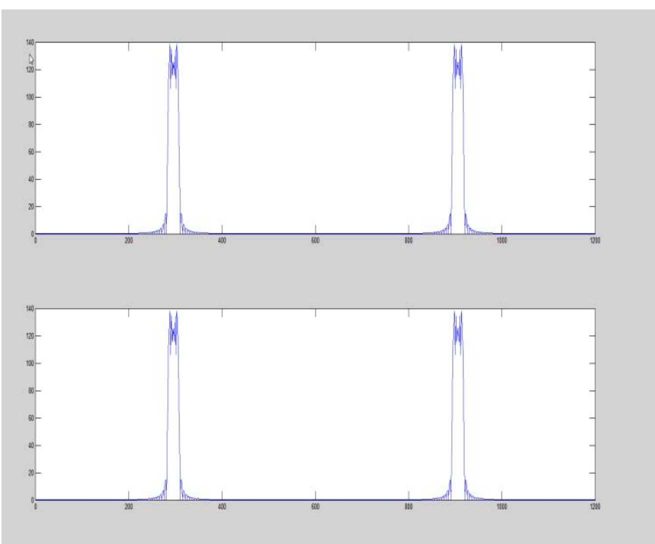

Fig 6 Transmitted and received spectrum

Once the echo is received, the transmitted signal is mixed with received signal to get the resultant frequency from which the range is calculated. Range calculation for SFCW is done using IFFT (Inverse FFT). Fig 7 shows the IFFT plots.

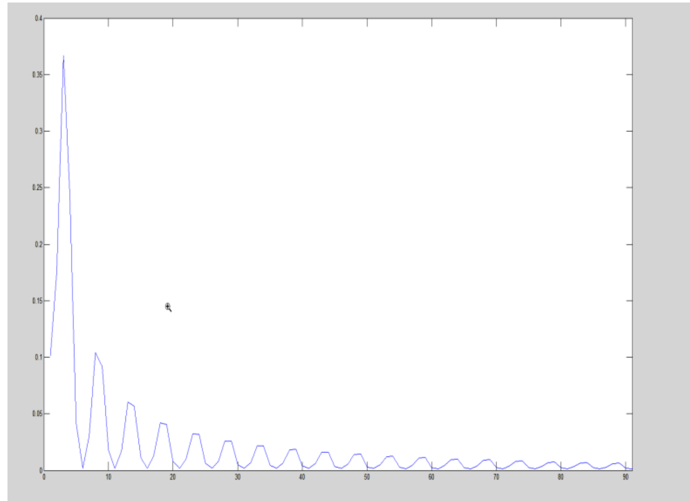

Fig 7 IFFT plot for a range of 5m

V. PLL BASED SFCW SIMULATIONS

The PLL is used to generate SFCW signals at C-band. The spectrum is captured on spectrum analyzer as shown in Fig 8

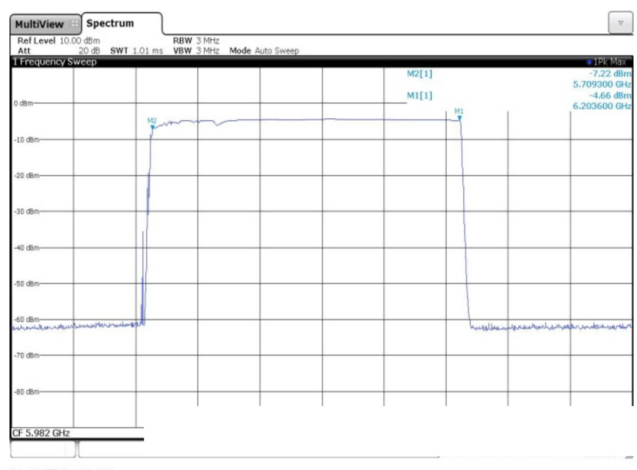

Fig 8 SFCW on spectrum analyzer

Received frequency is mixed with Transmitted frequency and beat frequency signal is conditioned using STC (Sensitivity time control).Resultant beat frequencies for different range resolutions are captured in CRO. Fig 9 shows the plot when target is 4mtr away. Fig 10 shows the plot in which two targets are present, one 3mtr away and other one 4mtr away. Fig 11 shows the resolution which the designed hardware can achieve. 0.3 mtr of resolution has been achieved. As per the requirement of sensor, the nearby target has to be displayed .The nearby target results in lower beat frequency compared to far range targets. After IFFT analysis the different bins are compared to find out the nearby target and displayed.

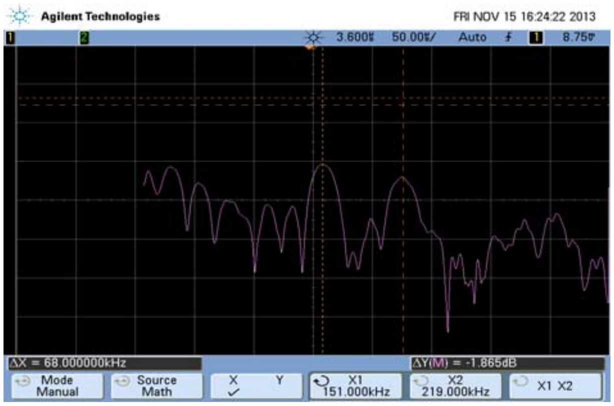

Fig 9 .Output when two targets at 6mtr and 8mtr

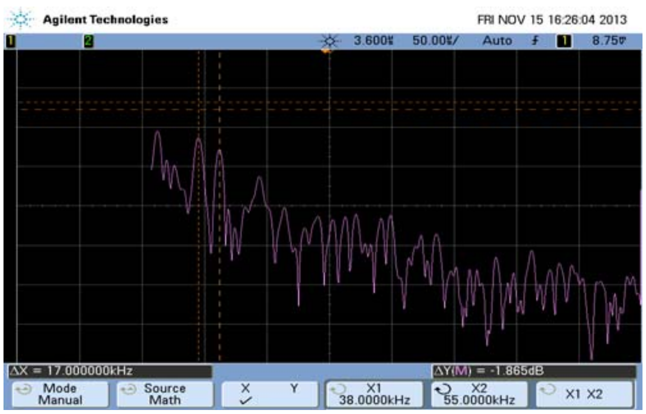

Fig 10 Two targets at 3 mtr and 4 mtr

Fig 11 Two targets with separation of 0.3mtr

CONCLUSION

An SFCW based radar proximity sensor capable of detecting targets within a range of 10mtr with a range resolution of 0.3mtr has been discussed. It has been realized using fast acting synthesizers, and compact signal processing hardware. It is Cost effective and works with current technology. Proposed proximity sensor can be used in all types of weather conditions.

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BIODATA OF AUTHORS

Fouziya C - Obtained her B.Tech degree in Electronics and Communication from Govt collage of Engineering, Kannur in 2009. She is currently working as a senior engineer in Central development & engineering (BEL), Bangalore. Area of specialization is in Radio frequency transmitters and receivers and ultra low phase noise synthesizer.

T.Venkatamuni – Obtained his B.Tech from Sri Venkateswara University College of Engineering, Tirupati in 1999. Also he has obtained M.E in Communication Systems from Regional Engineering College Tiruchirappalli in 2001. He joined Central Research Laboratory-Bharat Electronics Ltd. Bangalore, in 2001 and since then he is working in the RF and Microwave group as a Member Research Staff. Presently he is working as a Manager in Central Development and Engineering- Bharat Electronics Ltd. He has worked on Adaptive signal processing for anti jamming, Power amplifiers linerarizers and FMCW radars reflected power cancellation. His area of interests includes handheld RF Transceivers and ultra low phase noise synthesizers.

Vikas Kumar-Obtained his B.E from UVCE Bangalore in 2012.He joined BEL 2012 and since then he is working in RF group as Deputy Engineer. He has worked on L-Band transmitter and receivers, Signal processing for proximity sensor, controller for radio relays, synthesizers and Signal processing for Digital Receiver.

Kalyani Murthy – Kalyani Murthy joined BEL in 1985 at Tactical Communications group after graduating in Electronics & Communications Engineering from BIT, Ranchi University. She has worked on HF & VHF Man pack and handheld Radio systems and associated Frequency synthesizer subsystems. Moved to Core RF design group in 2000 and involved in design of various RF Trans-receiver modules and Frequency sources for Communications and Radar systems. Worked at Corporate Strategic Planning division from 2007-12. Currently heading the RF components (RFC) group of Central D&E since 2012.