

# PORTABLE DECHIRP-ON-RECEIVE RADAR

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## Abstract

Sensor Concepts Inc. has prototyped a fast, lightweight, dechirp-on-receive radar called the SCI-Lr to provide the capability of a range instrumentation radar in a highly portable package. The small weight, size and power requirements of the SCI-Lr allow a variety of new deployment options for the user including in a small general aviation aircraft or on a mountaintop that is accessible only by four wheel drive.

Pulse rates up to 20 KHz enables investigation of high Doppler bandwidth phenomenon such as ground vehicle microdoppler features. The dual integration from dechirp-on-receive matched filtering in fast time and Doppler processing in slow time provides high sensitivity with low output power. Planned enhancements of waveform bandwidth up to 2 GHz, frequency operation between .2 and 18 GHz and pulse-to-pulse polarization switching will provide high information content for target discrimination.

The flexibility provided by the hardware is augmented by software tools to examine data in near real time to monitor data quality and sufficiency. A variety of applications are being investigated including RCS measurement, SAR and ISAR imaging, Ground Moving Target Indication, and signature collection for ATC.

**Keywords:** Measurement systems, Radar imaging

## 1. Introduction

Sensor Concepts has been known for producing compact, wideband, linear frequency modulated homodyne radar systems. These radars are optimized for use at ranges from tens to hundreds of feet. They can be employed at longer ranges, but range resolution must be decreased to counteract the effects of increasing phase noise at far range.

The development of the Long Range radar (SCI-Lr) was prompted by the need for a small but highly capable radar that would be able to operate at ranges from hundreds of feet to several miles or farther. This longer range capability required a design approach using a digital waveform

generator and a dechirp-on-receive demodulation technique. The result is a system that has phase noise that is essentially independent of range. This allows high range resolution at any range.

## 2. Radar Hardware

The SCI-LR radar design supports frequencies from .2 to 18 GHz. Flexibility in bandwidth, pulse rates and number of digitized samples has been built into the design to allow for a variety of chirp waveforms. Multiple chirp waveforms provide for frequency band multiplexing on a pulse to pulse basis even at high Pulse Repetition Frequency (PRF) rates. The use of a 500MHz A/D converter allows for an extremely large alias free range in the slant range even when operating with high resolution waveforms.

Figure 1 shows a block diagram of the radar system design. The current engineering development prototype contains a subset of these functions: one A/D channel and polarization have been implemented and, at the time of this writing, the Raid Array, GPS and tape backup have not been integrated.

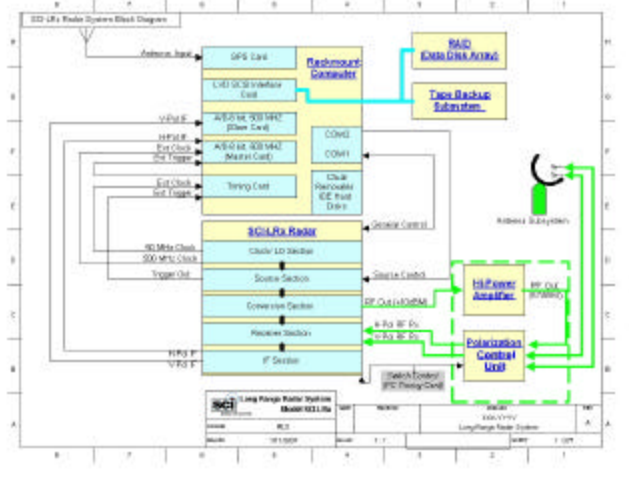


Figure 1:Lr Radar Block Diagram

### 3. Setup and Data Acquisition Software

System setup and data acquisition functions are controlled by the user using a LabVIEW interface. Chirp Bandwidth, center frequency, receive swath position and width and PRF can be selected to optimize the measurement for the target of interest.

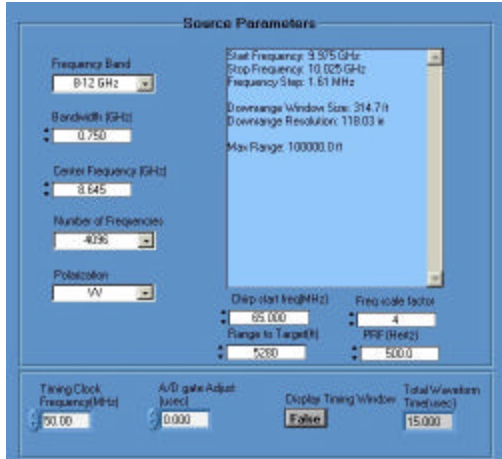


Figure 2: Source Configuration Setup

Data can be acquired in one of two modes: Continuous record or multiple pulse capture. The first allows data to be collected over indefinite intervals but has a lower maximum PRF. The second allows higher PRFs but restricts continuous recording duration based on A/D memory depth.

In the continuous record mode, the data is downloaded from the A/D board after each pulse and is buffered in PC memory or is immediately written to disk. Currently the maximum PRF supported in this mode is 3 KHz at 4096 samples/pulse. System optimizations are expected to double the PRF rate.

In the multiple pulse capture mode, a set of pulses is captured by the A/D and is downloaded to the radar after the set is complete. The maximum PRF in this mode is 20 KHz. The maximum amount of data captured in each set of pulses is limited by the onboard memory of the A/D board. Depending on configuration, this memory can be as small as 8 Mb or as large as 2 Gb.

In either mode, once data has been read from the A/D memory, successive pulses can be coherently summed before being written to disk. This allows high energy on target but low I/O throughput rates in the case that the target Doppler bandwidth is significantly lower than the radar maximum PRF.

### 4. Data Reduction Software

Data reduction includes functions to improve signal to noise and signal to clutter, locate and register targets, motion compensate and form images.

#### 4.1 Convert Raw to Scd

The first processing step in the data reduction is to convert the raw A/D stream into SCI's native ".scd" data format. This process includes the following steps:

- 1) Integrate and decimate successive pulses (optional)
- 2) Hilbert transform (see [Rab])
- 3) Residual video phase correction (see [Car])
- 4) Select range sub swath (optional)
- 5) Remove Background Clutter (optional)

Step 5, Remove Background Clutter is performed in two parts. First a clutter range profile is calculated for each Coherent Processing Interval (CPI), by averaging frequency samples across all pulses in a CPI, then range resolving the averaged frequency samples. This is equivalent to calculating a range-Doppler image of the CPI and retaining the range profile at Doppler filter 0. Clutter Profile calculation is shown in Figure 3.

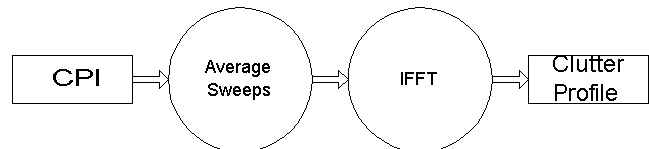


Figure 3: Estimate CPI Clutter Range Profile

Next, clutter profile estimates at adjacent CPIs are used to estimate clutter for each CPI under test. In order to make the process robust to small movements in the radar antenna, the clutter profiles must be phase adjusted to be in phase with the clutter profile for the CPI under test. This is shown in Figure 4. In the diagram, four adjacent CPIs are used. In practice this number usually larger.

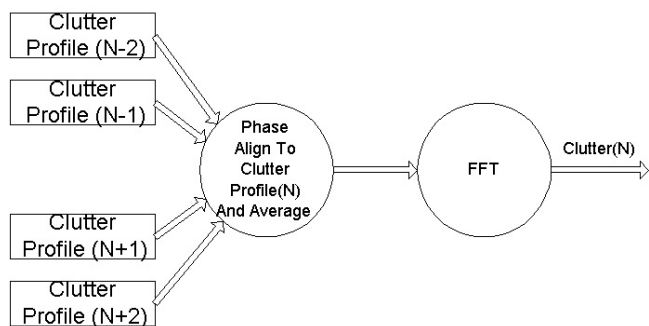
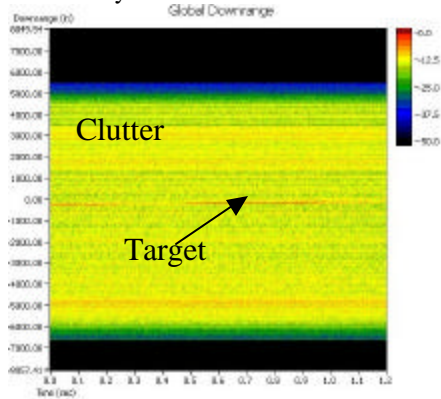


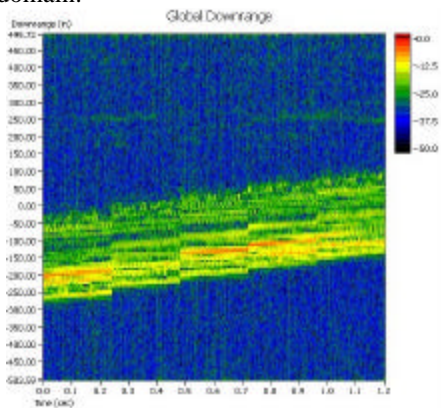
Figure 4: Estimate CPI Clutter

Figure 5 shows an example downrange plot of a small ground moving target in noise and ground clutter. The vertical axis is downrange and the horizontal is time. The data dimension is 2048 by 10240 points, which corresponds to 5 successive CPIs. The target is near the center of the image, but is obscured by clutter.



**Figure 5:Raw DownRange**

Figure 6 shows the same data after downrange and Doppler filtering, reduction in downrange and crossrange and clutter removal. The target position across the five CPIs is now very visible. The amount of data has been reduced by a factor of 256. Signal to noise has been improved by 12 dB and signal to clutter has been improved by over 20 dB in the range profile domain.



**Figure 6:Filtered and Reduced DownRange**

The filtering and reduction applied in the raw data to .scd converter uses parameters that have been specified by the user. It does not attempt to locate the target and adapt processing based on target location. The next function to be described uses target position and profile shape to line up then reduce the data in downrange.

#### 4.2 DownRange Align and Reduce

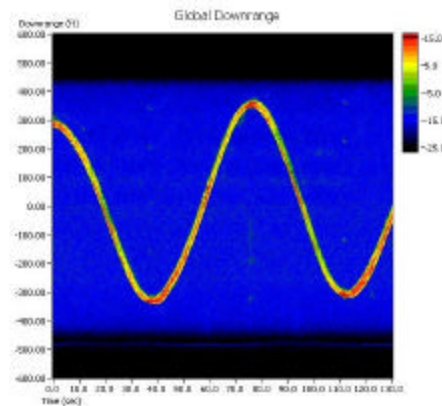
The downrange align and reduce function is used to reduce data when the target is moving in a nonlinear manner and is

visible above the clutter and noise when range resolved. The processing steps include:

- 1) Noncoherent integration of profiles
- 2) Amplitude compress profiles
- 3) Find IF filter range rolloff points
- 4) Cross correlate profiles
- 5) Robust curve fit of correlation shifts
- 6) Reduce range swath

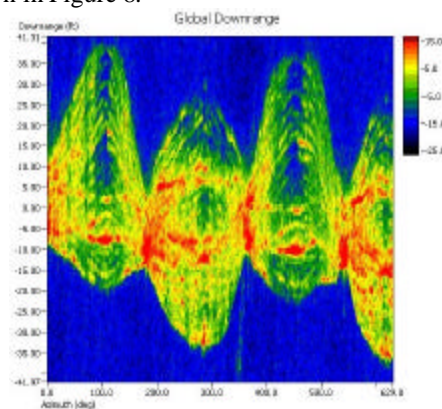
Figure 7 shows circle data collected on a small boat (see section 5.2) before alignment. In this example no reduction has been performed in the raw to .scd data converter.

Figure 7 illustrates the benefit of using a very high speed A/D converter and a large associated IF bandwidth. The system was able to measure a 1000 feet range swath with eight inch range resolution!



**Figure 7:Raw DownRange**

The data was downrange aligned and reduced. The results are shown in Figure 8.



**Figure 8:Aligned and Reduced DownRange**

For circle data, the target downrange history can be used to estimate the angle traveled during the run. The idea is that the target downrange position approximates a sine function

vs. time and the number of periods of the sine indicates the angle traveled by the target.

The modified covariance method is used to improve the resolution of the estimate (see [Mar]). A PSD is calculated of the series defined by the target downrange position over the run. The position of the peak of the PSD in Figure 9 indicates the angle subtended by the run. In this case 1.75 periods (which translates to an angle of about 630 degrees) has been estimated, which agrees with a visual comparison to Figure 7.

This method calculates an average angle rate during the run that is generally good enough to provide an angle for the motion compensation polar reformatting. If precise cross range scale factor is required for an image frame or the angle subtended over the frame is large, the local angle rate must be obtained in some other manner.

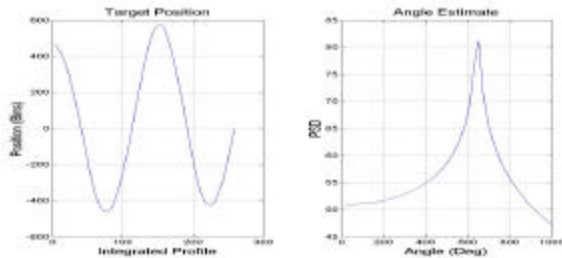


Figure 9: Angle Extent from DownRange Position

After the data has been aligned and range reduced, the motion compensation can be run efficiently on the reduced data set.

## 5. Applications

### 5.1 Ground Target Measurement

The Lr Radar participated in a ground target signature collection at the Naval Air Warfare Center's China Lake facility in 2001. The site was atop a mountain, overlooking a steep valley on the north ranges. The Lr was carried up the steep dirt road in the back of a 4 wheel drive SUV.

System parameters are listed in Table 1. Noise Equivalent Radar Cross Section (NERCS) is the radar cross section of a target that would have the same power as system noise at the slant range listed in the table.

Table 1: Ground Target Radar Parameters

| Radar Parameters for Ground Targets |                           |
|-------------------------------------|---------------------------|
| Center Frequency                    | 8.65 GHz                  |
| Chirp Bandwidth                     | 0.75 GHz                  |
| PRF                                 | 10 KHz (20 KHz available) |
| Range Resolution                    | 8"                        |

|                        |                   |
|------------------------|-------------------|
| Alias Free Range       | 1024 ft !         |
| Doppler Resolution     | 5 Hz (.27 ft/sec) |
| Max. Unambiguous Speed | $\pm 275$ ft/sec  |
| Peak Power             | 0.4 W             |
| Antenna Gain           | 32 DBi            |
| Slant Range            | 8600 feet         |
| NERCS (Raw)            | 14 dBsm           |
| NERCS (Processed)      | -51 dBsm          |

No high power amplifier was needed because of the dual integration gains of linear frequency modulation in fast time and Doppler processing in slow time. Integration gain was 65 dB.

Figure 10 shows a range-Doppler image of a water truck. The vertical (Y) axis is range in feet and the horizontal (X) axis is range rate in ft/sec. A small subset of the available image in range and Doppler was selected for display. About 1/8 of the Doppler extent and 1/10 of the range extent are shown.

The center X position corresponds to zero range rate. The bright vertical line at this location is the return from stationary ground clutter. X positions to the right of the clutter line correspond to an approaching target. The truck was approaching the radar so its skin return is visible to the right of the clutter line. It appears at about four ft/sec closing speed and can be seen as a line of bright pixels from -25 to 0 feet in range. A slice through these pixels would create a downrange profile of the truck.

The truck was spraying a plume of water from the back. The spray was going away from the radar so it appears on the opposite (opening speed) side of the ground clutter line.

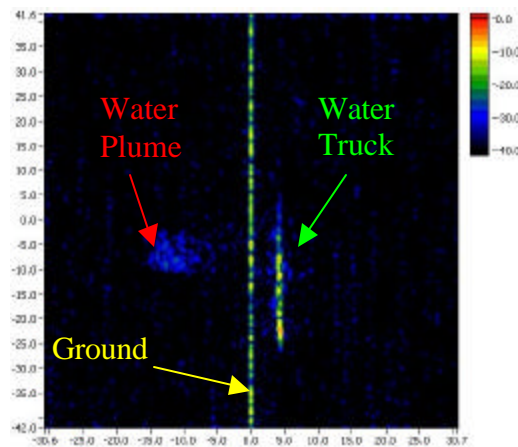


Figure 10: Water Truck

Figure 11 shows an image of a ZSU tracked vehicle. The vehicle was moving away from the radar. Its skin return is the brightest pixels to the left of the ground return line. The tread is the oval-shaped feature that encloses the ZSU skin. The top of the tread is visible at twice the target body range rate. The bottom tread is in contact with the ground and so has essentially zero range rate. The front and back of the tread show the speed transition from twice target speed to 0 and back.

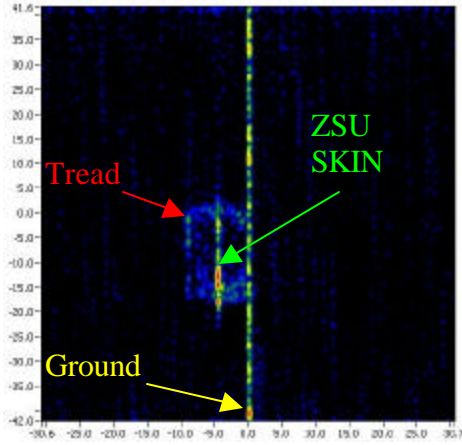


Figure 11: ZSU Tracked Vehicle

### 5.2 Ship Target Measurement

The Lr radar was used to collect ship signature data for a Navy sponsored proof of concept demonstration at Virginia Beach Va. in April 2002. The target under test was the 60 foot fishing boat shown in Figure 12.



Figure 12: "Flying Fish" Target

System parameters varied for this collection over a variety of PRFs. Range to the target was changed from 1 Nmi to 5 Nmi.

Processed NERCS varied due to changing processing gain and range to the target. Parameters are listed in Table 2.

Table 2: "Flying Fish" Radar Parameters

| Radar Parameters for "Flying Fish" |                  |
|------------------------------------|------------------|
| Center Frequency                   | 8.65 GHz         |
| Chirp Bandwidth                    | 0.75 GHz         |
| PRF                                | 200 Hz - 10 KHz  |
| Range Resolution                   | 8"               |
| Alias Free Range                   | 1024 ft          |
| Doppler Resolution                 | 2-5 Hz           |
| Max. Unambiguous Speed             | $\pm 275$ ft/sec |
| Peak Power                         | 0.4 W            |
| Antenna Gain                       | 35 DBi           |
| Slant Range                        | 1 Nmi, 5 Nmi     |
| NERCS (Raw)                        | 15 dBsm @ 1 Nmi  |
| NERCS (Processed)                  | -41 dBsm @ 1 Nmi |

Several circle runs were collected on the target at 1 Nmi. The radar was operating in continuous record mode using PRFs between several hundred Hz and 2 KHz. Figure 13 shows an example image after motion compensation. In this case the PRF was 370 Hz and the coherent processing interval was 1/3 second.

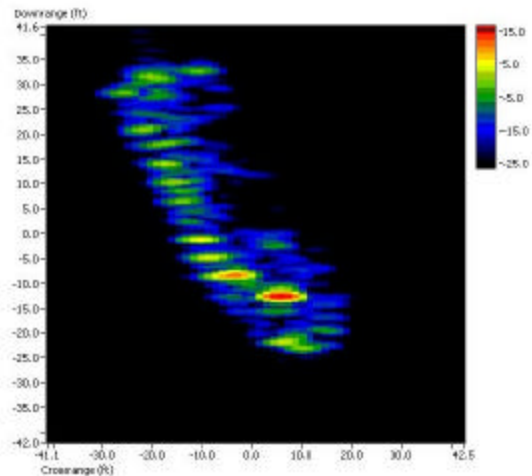
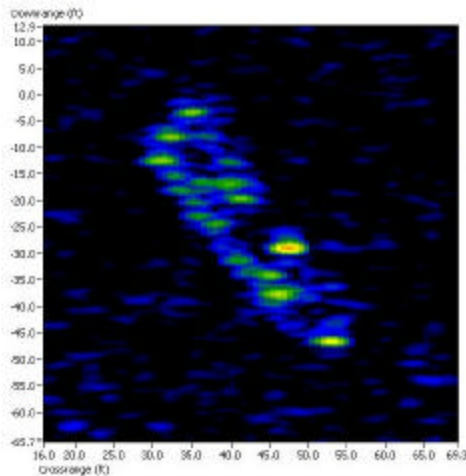


Figure 13: Flying Fish at 1 Nmi

Figure 14 shows the same target with a similar image orientation at 5 Nmi. The data was collected in multiple pulse capture mode. The PRF employed was 10 KHz. Coherent processing interval was 0.2 seconds.



**Figure 14: Flying Fish at 5 Nmi**

## 6. Conclusion

Sensor Concepts has prototyped a digital dechirp-on-receive radar that is compact, flexible and highly portable. This prototype has demonstrated the ability to collect high range resolution, very wide downrange swath data at high PRF rates, using low peak power.

The prototype will be extended in two directions: more functionality in the same size package, or the same functionality in a much smaller package.

The more capable system will have up to 2 GHz of

bandwidth per pulse and can operate from .2 to 18 GHz. It will change frequency, bandwidth, polarization and receive swath on a pulse to pulse basis. It will have a similar size and weight to the prototype system, resulting in state of the art measurement capability in a highly portable form factor.

The goal of the smaller system is to aggressively shrink the Lr prototype. Initial design studies indicate are that the Radio Frequency equipment can be fit into a soup can sized package! The intended platforms for this system are a tactical UAV or an imaging Synthetic Aperture Radar (SAR) / Ground Moving Target Indicator (GMTI) seeker. In addition to the hardware studies, algorithm development for GMTI and SAR modes are underway.

Both designs will result in wideband, highly diverse measurement sensors that can support high range resolution and provide PRFs capable of measuring interesting target modulation properties. This opens up a wide range of applications in test and measurement, and ground, sea and air based platforms.

## 7. References

- [Rab] Rabiner, L. R. , Gold, B. Theory and Application of Digital Signal Processing, Prentice Hall 1975, pp 70-73.
- [Car] Carrara, W. G. , Goodman, R. S., Majewski, W.G, *Spotlight Synthetic Aperture Radar Signal Processing Algorithms*, Artech House 1995, pp 501-506.
- [Mar] Marple, L. S. Jr., *Digital Spectral Analysis with Applications*, Prentice Hall, 1987, pp 222-224.