COHERENT MULTI-FREQUENCY-BAND RESOLUTION ENHANCEMENT FOR SYNTHETIC APERTURE RADAR

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1. INTRODUCTION

This paper presents a method whereby multi-frequency-band SAR systems can enhance the range resolution. If multiple signals are coherent and cover disjoint frequency bands, they can be combined into a single signal which can be processed using slightly modified traditional SAR processing algorithms, resulting in an image with a range resolution enhanced by summing the constituent bandwidths.

Combining multiple pulses to improve range resolution is not a new idea. Algorithms for stepped-frequency SAR have been in use for many years. This paper extends the work done by Richard Lord et al. [1, 2, 3]. Many of the restrictions previously placed on combining multiple chirps are greatly relaxed in the algorithm proposed in this paper. Principally, the individual chirps do not need to be closely spaced in frequency.

Synthetic Aperture Radar (SAR) has proven useful in many applications, including reconnaissance, surveillance, mapping, change detection, and environmental studies. The use of multiple frequencies with high resolution augments the utility of SAR in each of these applications. Advances in SAR are consistently opening possibilities for more capable SAR systems, with finer resolution and multiple frequencies. Range resolution is a key performance parameter constantly being improved upon to obtain better and more useful SAR images. The resolution is dependent on the bandwidth of the radar chirp.

Bandwidth increases are difficult, especially at lower frequencies, due to a number of factors: 1. Many bands of the frequency spectrum are protected and SAR operation is prohibited in those bands [4], 2. Radar hardware, including power amplifiers and antennas, is designed to operate at specific frequencies, and very high bandwidth hardware is expensive, 3. Each increase in bandwidth increases the sampling and data storage requirements.

A system that can sidestep these issues and provide a large bandwidth, even when traditional design limits prohibit such an arrangement, would prove extremely useful. This paper sets forth the theory that makes such a system possible and presents two SAR systems, the NuSAR and MicroASAR, that have been designed capable of demonstrating this ability.

2. THE THEORY OF COHERENT MULTI-BAND RESOLUTION ENHANCEMENT

This paper presents a general development, expanding on the presentation in [1, 2, 3], for how two or more separate, but coherent, signals spanning disjoint frequency bands, can be combined to give a resolution dependent on the sum of the bandwidths. This is achieved by shifting the signals in frequency and time (Fig. 1), summing them, and using modified versions of common processing algorithms to form the SAR image. The modifications to the processing algorithms makes it so that the center frequencies of the different chirps need not be close in frequency. Simulated data shows the resolution improvement for a single target (Fig. 2) and for a pair of targets (Fig. 3.

This method easily lends itself to situations where the radar chirp has to skip a frequency band and when hardware constraints make large bandwidth systems impractical. Because each signal stream can be recorded separately, it sidesteps some of the sampling and storage requirements that greatly contribute to the difficultly and expense of large bandwidth systems.

3. SAR SYSTEMS CAPABLE OF COHERENT MULTI-BAND RESOLUTION ENHANCEMENT

In order to test this theory with actual SAR data, we use two separate SAR systems developed by Brigham Young University (BYU) and ARTEMIS Inc., the NuSAR and the microASAR, each of which is capable of forming images using coherent multi-band resolution enhancement.

The NuSAR [5] was developed as part of the U.S. Naval Research Laboratory's (NRL) DUSTER program in a team effort with BYU, ARTEMIS Inc., Space Dynamics Laboratory, and NRL. The NuSAR is designed for unmanned aircraft system (UAS) flight operating at L-Band and X-Band at 500 MHz bandwidth giving a 30 cm resolution. The microASAR [6, 7] is a small, light-weight SAR designed specifically for low-power and low-altitude operation. The system operates in the C-band with a bandwidth that can be set between 80 to 200 MHz. Different frequency bands, such as L-band and X-band, are available with additional RF hardware. The full version of this paper will contain SAR images from these two sensors.

4. REFERENCES

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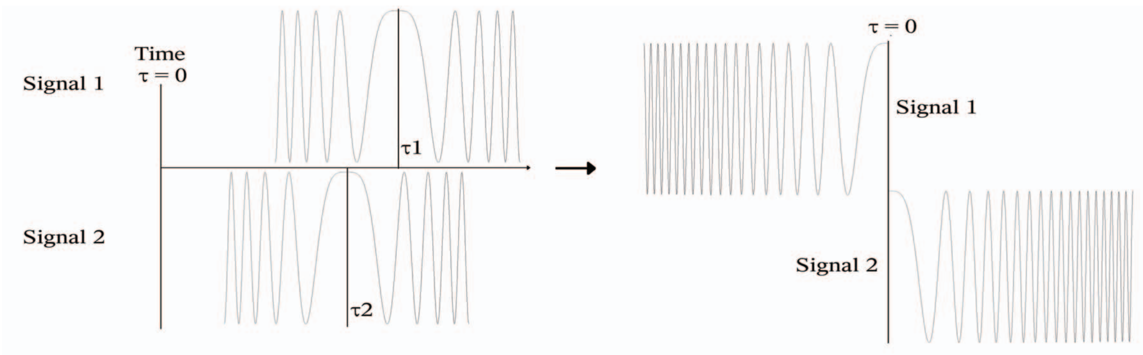

Fig. 1. Two coherent SAR pulses at different center frequencies (shown without the carrier) are transmitted at times τ_1 and τ_2 (left). In order to coherently combine the two signals to increase the total bandwidth, the signals must be shifted in time and frequency such that the timing difference is removed, the zero frequency points of the signals line up, and the signals span separate mixed-down frequency bands (right).

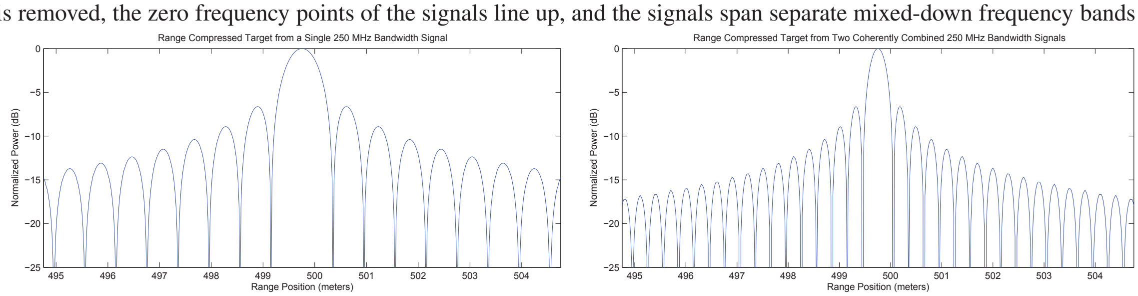

Fig. 2. A simulated point target is range-compressed with a single 250 MHz bandwidth signal (left) and two coherently combined 250 MHz bandwidth signals (right). The measured resolution of the single band image on the left is 57.15 cm while that of the double band image on the right is 28.53 cm.

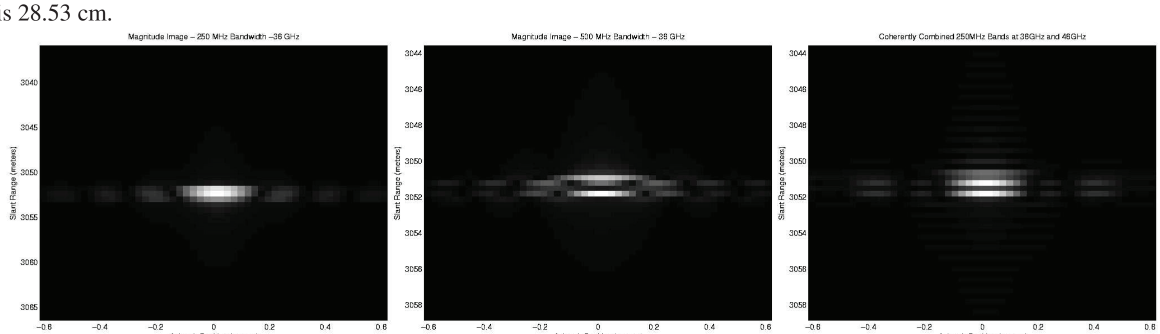

Fig. 3. Fully compressed simulated SAR images of two point targets separated by 0.75 m in slant range, processed with the RDA. The leftmost image is of single 250 MHz bandwidth data with a center frequency of 36 GHz. The resolution is 60 cm which is not sufficient to clearly separate the two targets. The center image is from single bandwidth data with a resolution of 30 cm at 36 GHz. The image at right is formed from two separate 250 MHz bandwidths, at 36 GHz and 46 GHz, which combined give an effective bandwidth of 500 MHz. The two targets are clearly visible in the rightmost two images, showing that coherent multi-band resolution enhancement performs as well as single band data of the same bandwidth. The data is oversampled in the azimuth direction, visually stretching the targets. The azimuth resolution is measured at 16 cm.

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