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High-resolution ultrawideband SAR based on OFDM architecture

SUMMARY: This white paper addresses the proposal of research aimed at the development of detailed model-based description of high-resolution potentially jamming-resistant portable synthetic aperture radar (SAR) system with rapid radar image transmission capabilities for complete battle-scene reconstruction. High resolution of obtained imagery and resistivity to certain types of jamming will be achieved via using ultrawideband OFDM-modulated waveforms. Using OFDM transceiver structure – heavily dependent on digital processing, and, thus, readily implementable in VLSI architecture – will provide portability and simplify image processing. Possibility of real-time image transmission will be addressed by proposing to use the same transceiver structure for data communication purposes. The overview below lists current achievements in modeling UWB-OFDM SAR system and contains propositions on the future directions of research.

1. WHY OFDM?

Orthogonal frequency division-multiplexing (OFDM) is a viable modulation method for sampling-based ultrawideband applications due to the ease of waveform generation and processing and inherent excellent multi-path characteristics of resultant signal. Conceptually, it can be thought of as a "discrete linear frequency modulation," because the signal is constructed out of a number of narrowband sinusoidal pulses representing OFDM sub-bands in spectral domain. Each sub-band is centered around a sub-carrier. These sub-bands are designed in a fully orthogonal manner, so that they result in zero interference at the precise locations of sub-carriers, thus making it possible to extract amplitude and phase of each sub-carrier independently. The resultant waveform, therefore, will exhibit wideband characteristics desirable for high-resolution radar performance, yet at the same time, since it is essentially a linear combination of narrowband signals, will provide for ease of system design and data processing. Selection of particular sub-bands on a pulse-by-pulse basis in OFDM also affords a capability of effectively 'shutting off' narrowband interferers and jammers from the radar processing. Furthermore, OFDM transceiver architecture is inherently heavily based on digital implementation and, thus, major portion of it can be built using relatively inexpensive and highly integrated components, providing for low cost and portability.

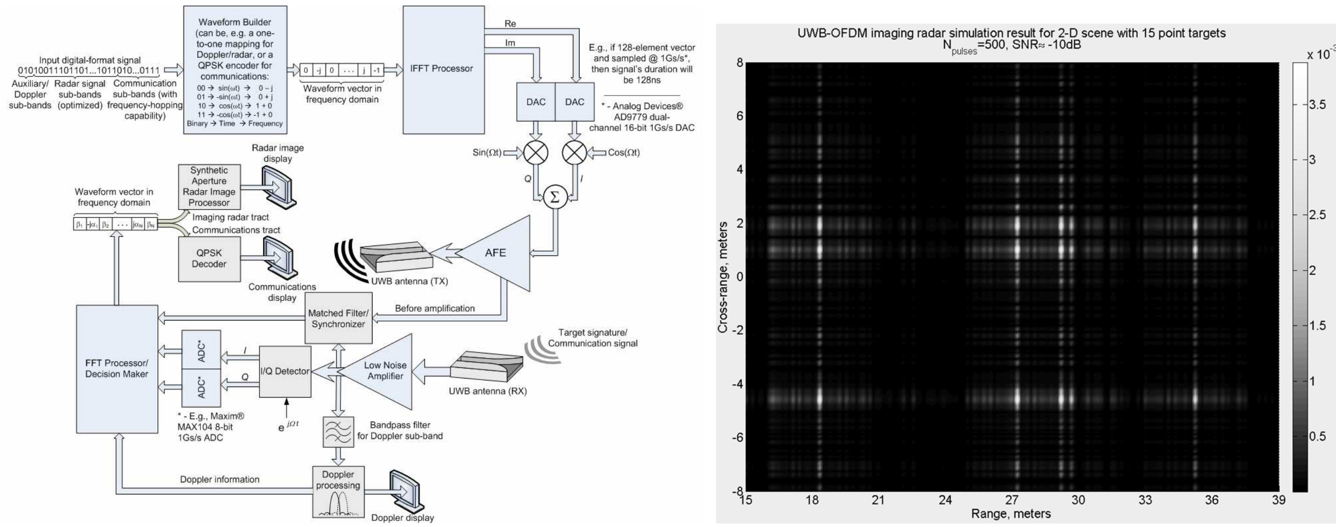
In summary, the advantages of using OFDM in radar are:

- Waveforms are generated digitally with possibility of pulse-to-pulse shape variation
- Ease of narrowband jamming/interference mitigation by simply turning off certain sub-bands
- Noise-like waveforms for increased LPI/LPD (low probability of intercept/detection)
- Multi-band approach affords benefits of frequency-hopping, but on UWB scale
- High resolution and good multi-path potential
- Current technology allows for relatively inexpensive implementation
- Same architecture can be used to transmit large amounts of image data in real time
- Flexible usage of sub-bands: some can be used for Doppler/location/voice communication…

Current research work is based on simulation analysis of imaging performance of UWB-OFDM stripmap SAR. It shows clear potential of such a system – assuming realistic system components and operating conditions (to be described below) – to perform imaging with approximately 25 – 100 cm of range resolution at the ranges between 15 and ~40 meters.

2. SYSTEM DESCRIPTION

Figure 1(a) shows a block-diagram of UWB-OFDM radar system. Transmitter portion of the system implements conventional basic OFDM architecture. Signal is originally created as a binary code representing sub-bands in frequency domain. Its conversion to "digital time domain" is performed by the IFFT block, implemented either as a discrete microprocessor element, or as part of an SDR system. The signal generated by IFFT block remains in the "digital domain" until it is sampled by DAC at a desired rate as to produce the required number of samples equal to the number of sub-bands. Selecting a high-speed DAC with 1 Gs/s sampling rate will, therefore, produce an N_{SB} nanosecond signal interval, where N_{SB} is the number of sub-bands. Subsequent transmitter components should be implemented in analog form and such considerations as linearization of AFE to accommodate 1 GHz bandwidth, signal integrity in integrated interconnect, peak-to-average power ratio control and wideband antenna performance characteristics should be addressed. The receiver side can be implemented using approximately the same components in reverse order. After AFE the carrier is removed by means of carrier demodulation, which is a challenging topic for UWB-OFDM communications due to the requirement of accurate timing synchronization; however, this requirement has a different meaning for radar applications since transmit signal is known by definition. Downconverted time-domain signal is then fed to a high-speed ADC with the same sampling rate as the DAC in transmitter chain and time samples of the signal can be directly processed to obtain range information, or converted into frequency domain by means of FFT and used for cross-range imaging. If the link is used for communication purposes, output of FFT block is used to form received data vectors.



(a) **(b)**

Figure 1: (a) UWB-OFDM radar system block diagram;
(b) 2-D simulated image of the target scene with 15 point reflectors at SNR ~ – 10 dB (obtained using Simulink radar test-bench and Matlab processing based on backprojection)

3. CURRENT STATE AND FUTURE WORK PROPOSAL

"Proof-of-concept" simulation test-bench for UWB-OFDM stripmap SAR has been constructed and simulated radar imagery was obtained. UWB-OFDM imaging radar performance is modeled using Matlab® and Simulink®. The latter was used to build a waveform-based simulator test-bench that included signal generation, transceiver functionality and multi-target range-dependent environment model. The former was used to write and simulate scripts that extract target information from the received signals obtained from Simulink test-bench. Backprojection algorithms in fast- and slow-time domains (described in "*Synthetic Aperture Radar Signal Processing with Matlab Algorithms*," M. Soumekh, John Wiley & Sons, 1999) were modified for this system implementation. An example of 2-D target scene image containing 15 point reflectors with reflectivity ~12dB above clutter and receive signal SNR= –10dB is shown in Figure 1(b).

The following topics are identified for future work:

I. UWB-OFDM system architecture planning

System partitioning to ensure utilizing advantages afforded by OFDM. Selection of components for software-defined radio (SDR): ADC/DAC, FFT/IFFT processor, etc and AFE/antenna system components. Research of data processing algorithms (real-time vs post-processing). Research of multi-band vs single-band implementation (complexity vs performance trade-off). *Outcome:* full system schematics diagram and assembly plan.

II. Performance characteristics in multi-path environment with and without ECM

Multi-path channel modeling (theoretical and experimental). Simulation of system performance in following scenarios:

a. No jamming/interference environment (simulation study of performance upper bound)
b. Narrowband jammers/interferers environment (simulation study of adaptive sub-band 'zeroing' to avoid interference effects, and experimental study with strong narrowband signal sources)
c. Wideband jammers – 'radar signal counterfeiters' (simulation study with various jammer models)
d. Overwhelming wideband noise/jamming (model-based performance lower bounds estimation)

Outcome: performance characteristics bounds in various realistic sets of conditions.

III. UWB-OFDM radar system implementation characterization

Practical consideration of system features' impact on imaging performance, including:

a. Carrier phase offset and receiver PLL phase noise effects
b. I/Q imbalance
c. High peak-to-average power ratio (PAPR) in non constant-envelope signals
d. Bandwidth-limiting characteristics of platform interconnect

Outcome: analysis of system-specific errors and design guidelines to minimize their effect.

IV. UWB-OFDM radar system construction and testing