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Hardware Implementation and Verification of Parallelized Direct Digital Synthesizer (PDDS) using FPGA

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Introduction

❑ Background

- Synthetic Aperture Radar is radar sensor by using microwave
  - ✓ In generally, the resolution of the SAR is determined by the pulse width, the resolution is improved as the pulse width is small
  - ✓ Since it is difficult to reduce pulse width, SAR used chirp signal that easy to change the bandwidth

❑ Motivation

- Chirp signal can be generated in the analog and digital
  - ✓ In analog case, fever and harmonic frequently occur
  - ✓ In digital case, truncation occurs by the digital generation process

❑ Contribution

- Propose methods for compensating a phase error caused by the chirp signal digital
  - ✓ Curve fitting method
  - ✓ Parameter calculation method
- Performance analysis

Contents

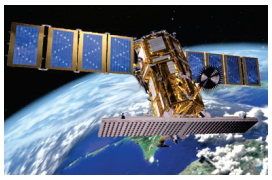
Related Works

Introduction

Related Works

❑ Synthetic Aperture Radar(SAR)

- Activity sensor that offers the image of target by using microwaves
- Regardless of the weather and day-light conditions, it can obtain a high-resolution images
- Operates on moving-platform
  - ✓ Satellites, UAVs, cars, and etc.
- Utilizing such as earth observation , acquisition of military information , natural disaster monitoring , and resource exploration



<KOMPSAT-5(2013.8.22 launched)>

Table. Frequency bands according to the center frequency and wavelenth

Frequency Band	Ka	Ku	X	C	S	L	P
Frequency [GHz]	40-25	17.6-12	12-7.5	7.5-3.75	3.75-2	2-1	0.5-0.25
Wavelength [cm]	0.75-1.2	1.7-2.5	2.5-4	4-8	8-15	15-30	60-120

Related Works

❑ Chirp signal - Linear FM(LFM) signal

➢ Chirp signal equation

$$x(t) = rect\left(\frac{t}{T}\right) Ae^{j\pi\beta t^2} \cdots (1)$$

Phase

➢ Instantaneous frequency are derived by (1)

$$f(t) = \frac{1}{2\pi}\frac{d\emptyset(t)}{dt} = \frac{1}{2\pi}\frac{d(\pi\beta t^2)}{dt} = \beta t$$

$A = amplitude$
$T = pulse\ duration$
$t = time\ variable\ in\ seconds$
$\beta = LFM\ rate\ or\ chirp\ rate$
$in\ hertz\ per\ second$

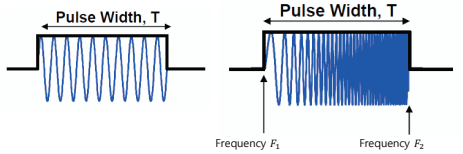
Related Works

❑ Characteristics of chirp signal

➢ In general, narrower the pulse duration, better the resolution.
➢ By increasing the bandwidth, chirp signal enhance the resolution.

$$\Delta R = \frac{c}{2}\frac{\tau}{} = \frac{c}{2B}$$

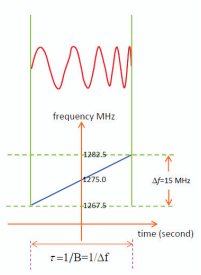
ΔR = resolution
c = speed of light
B = chirp bandwidth



Bandwidth = 1/T

Bandwidth $=\Delta F = F_2 - F_1$

<Example of ordinary pulse and chirp pulse>

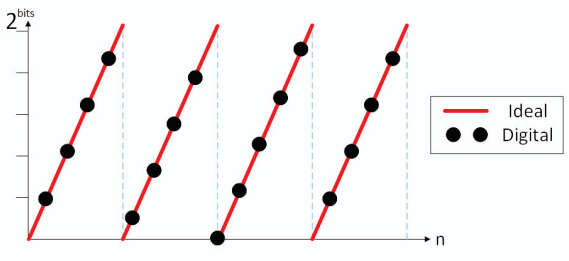


<Chirp signal>

Related Works

❑ Truncation

➢ In ideal case, no phase and amplitude truncation
➢ In practical case, phase truncation occurs from phase accumulator.

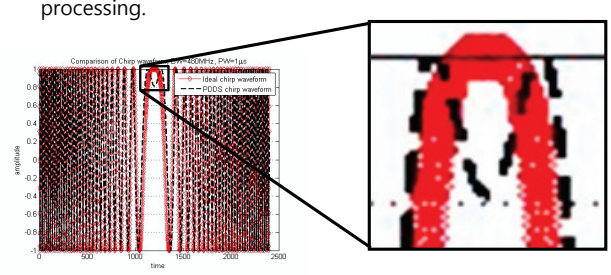


<Phase accumulator error sequence>

Related Works

❑ Phase truncation

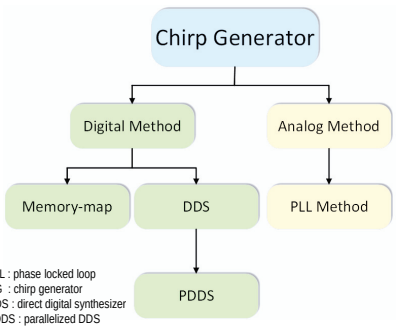
➢ Ideal chirp signal shows the characteristic of cosine function
➢ Conventional PDDS shows phase shift in the signal center
➢ Extract the error (phase shifting) and compensation by post-processing.



<Ideal signal and PDDS signal in time domain>

Related Works

❑ Classification-chirp signal



PLL : phase locked loop
CG : chirp generator
DDS : direct digital synthesizer
PDDS : parallelized DDS

<Chirp generator classification>

System Performance	Analog CG	Digital CG
FM noise	Good	Good
Frequency response	Good	Excellent
Linearity	Good	Excellent
N+1 compatibility	Degrade performance	Excellent
Complexity	Low	Moderate to high

<Comparison of analog CG and digital CG [1]>

	Memory-map	DDS
Memory device	ROM or PROM	Block RAM
Complexity	Easy	Hard
Flexibility	Low	High
Truncation	Low	High

<Comparison of Memory-map and DDS>

[1] Chua, Ming Yam, and Voon Chet Koo. "FPGA-based chirp generator for high resolution UAV SAR." Progress In Electromagnetics Research 99 (2009): 71-88.

Proposed method

Propose Method(1)

❑ Proposed method - curve fitting method

➢ Curve fitting method

1. Parameterize the phase output of Ideal signal and DDS signal
2. Calculate the difference between the two formulas
3. Compensate for the error in the frequency accumulator

➢ Example of curve fitting

✓ Ideal phase : $f_{ideal}(x) = 62.91t^2 + 2.024t - 188.5$

✓ DDS phase : $f_{PDDS}(x) = 62.91t^2 - 0.363t - 189.1$

➢ Example of calculation of difference between the two formulas

✓ Ideal frequency : $f'_{ideal}(x) = 125.82t + 2.024$

✓ DDS frequency : $f'_{PDDS}(x) = 125.82t - 0.363$

✓ Difference : 1.661

Performance Analysis

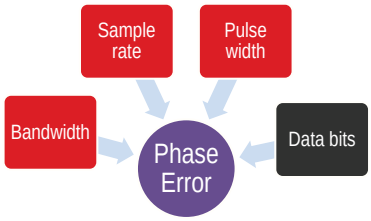
Propose Method(2)

❑ Proposed method – parameter calculation method

➢ Find the elements that affect the phase error, and calculate the relationship of the elements and the phase error

✓ Sample rate, Bandwidth, Pulse width, Data bits, and etc.

➢ Build the error model using the parameters



<The factors influencing phase error>

$$\frac{Bw}{(Fs/100)^2 \times T_p} \times k = Phase\ error$$

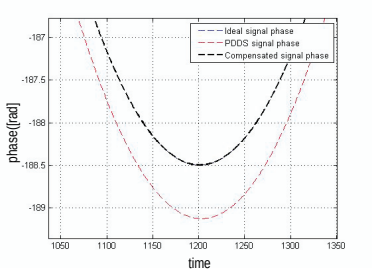
Bw : transmitted bandwidth
Fs : sample rate
Tp : transmitted pulse width

Performance Analysis – Curve Fitting Method

❑ Result

➢ As a result of compensating a phase error, ideal signal and the PDDS signal appears substantially overlap to graph

➢ Well reflected in the phase error to curve fitting data



<Ideal signal, PDDS signal and compensating phase of PDDS signal>

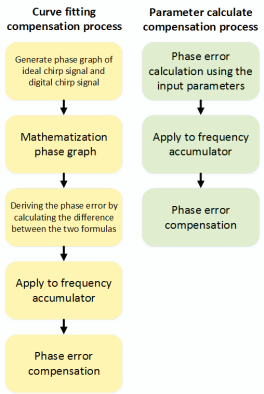
Performance Evaluation

❑ Improvement of the phase error compensation algorithm

➢ Compare curve fitting method with parameter calculate method

Parameter	Phase error		
	Curve fitting method	Parameter calculate method	Difference
Tp : 1.5 us Bw : 36 MHz Fs : 600 MHz	2.185	2.1846	-0.0004
Tp : 1.0 us Bw : 24 MHz Fs : 150 MHz	34.955	34.9546	-0.0004

< Comparison of phase error value >



< Comparison of the phase error compensation process >

Performance Analysis – Parameter Calculation Method

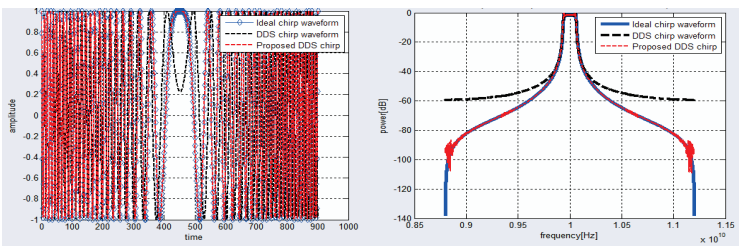
❑ Result

➢ Phase error compensation algorithm simulation

✓ Transmitted pulse width : 1.5μs

✓ Transmitted bandwidth : 32MHz

✓ Sample rate : 600MHz



<Comparison of Chirp waveform>

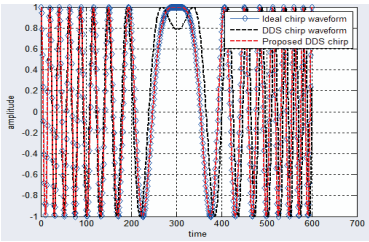
<Comparison of Spectrum>

Performance Analysis – Parameter Calculation Method

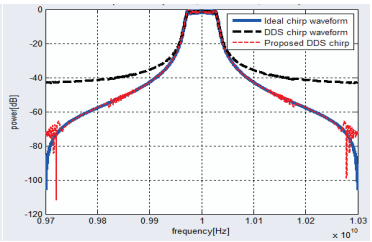
❑ Result

➢ Phase error compensation algorithm simulation

- ✓ Transmitted pulse width : 1.0μs
- ✓ Transmitted bandwidth : 16MHz
- ✓ Sample rate : 150MHz



<Comparison of Chirp waveform>



<Comparison of Spectrum>

Back up slide

Conclusion

Synthetic Aperture Radar(SAR)

Conclusion

❑ We verify that both curve fitting and parameter calculation method compensated phase error

❑ Curve fitting method can compensate the error even if amplifier or RF module is considered

➢ The more circuit or hardware extend, the more useful

❑ In parameter calculation method case, compensation process is simple

Synthetic Aperture Radar(SAR)

❑ RADAR

➢ RAdio Detection And Ranging

➢ Device using microwaves to measure the distance for detecting a observation target

❑ Transmitted and received signals

➢ Transmitted (Tx)

- ✓ Generally , pulse of triangular waveform

➢ Received (Rx)

- ✓ Changes appearing in the received waveform represent the features of the observation target
- ✓ Delay of the received signal (delay) represents the distance to the observation target

❑ Resolution

➢ Ability to distinguish two adjacent objects

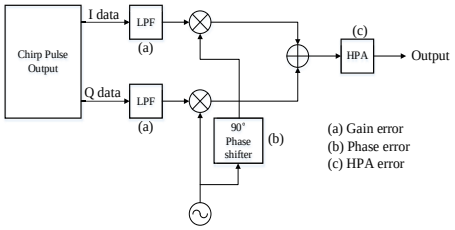
➢ $\Delta R = c\tau/2$

- ✓ c = speed of light
- ✓ τ = pulse width

Truncation

❑ Extraction of phase error

- ➢ Use a chirp signal generator of the DDS system
- ➢ Two major error is occurred in the process of generating DDS signal
  - ✓ Gain errors that occur through the LPF (low pass filter)
  - ✓ Phase errors that occur through the Phase shifter



<Chirp signal generation process and the error occurs block diagram>

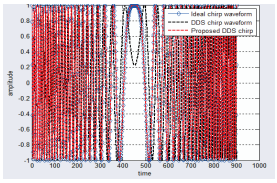
DDS : Direct digital synthesis

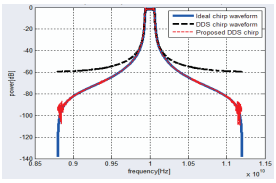
Result – Parameter Calculation Method

❑ Result

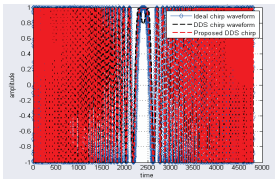
- ➢ Phase error compensation algorithm simulation

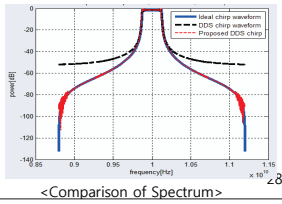
Transmitted pulse width : 1.5us
Transmitted bandwidth : 32MHz
Sample rate : 600MHz





Transmitted pulse width : 2.0us
Transmitted bandwidth : 64MHz
Sample rate : 600Mhz





<Comparison of Chirp waveform> <Comparison of Spectrum>

Propose – Curve Fitting Method

❑ Extraction process of phase error

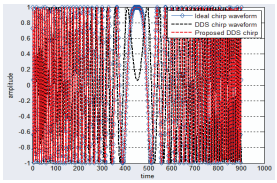
- ➢ When comparing the ideal signal and PDDS signal waveform , many error occurs in phase than amplitude
- ➢ After extracting the phase of each signal in time domain, to determine the error by a subtraction operation
- ➢ Curve fitting the error in the second order polynomial
  - ✓ Previously , using the cftool (curve fitting tool)
- ➢ Using the data which error has been curve fitting, and compensating the phase of the PDDS signal

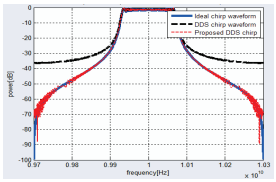
Result – Parameter Calculation Method

❑ Result

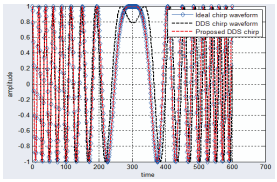
- ➢ Phase error compensation algorithm simulation

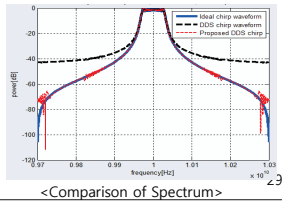
Transmitted pulse width : 1.5us
Transmitted bandwidth : 32MHz
Sample rate : 150MHz





Transmitted pulse width : 1.0us
Transmitted bandwidth : 16MHz
Sample rate : 150MHz





<Comparison of Chirp waveform> <Comparison of Spectrum>

Result

❑ Feature of DDS chirp signal generator

- ➢ Spectrum purity is not good by the signal generation method of Digital system