Study on Direct Digital Frequency Synthesis

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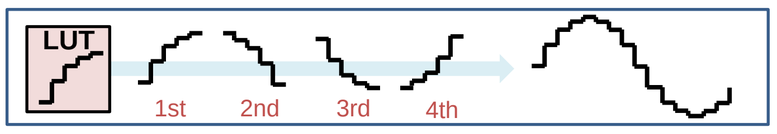
● Introduction & Objectives

- **Direct Digital Frequency Synthesis (DDFS)**
  - Generate periodic waveform in digital domain
    (ex. Sine waveform, Sinc waveform, Sawtooth waveform, …)
  - Control output frequency by frequency tuning word
- **Advantage of DDFS**
  - Performed in digital domain
    → Low cost, fast frequency converting
  - Implemented with integer arithmetic
    → Able to be implemented on any microcontroller

● Improve efficiency of DDFS

❖ Quadrature method

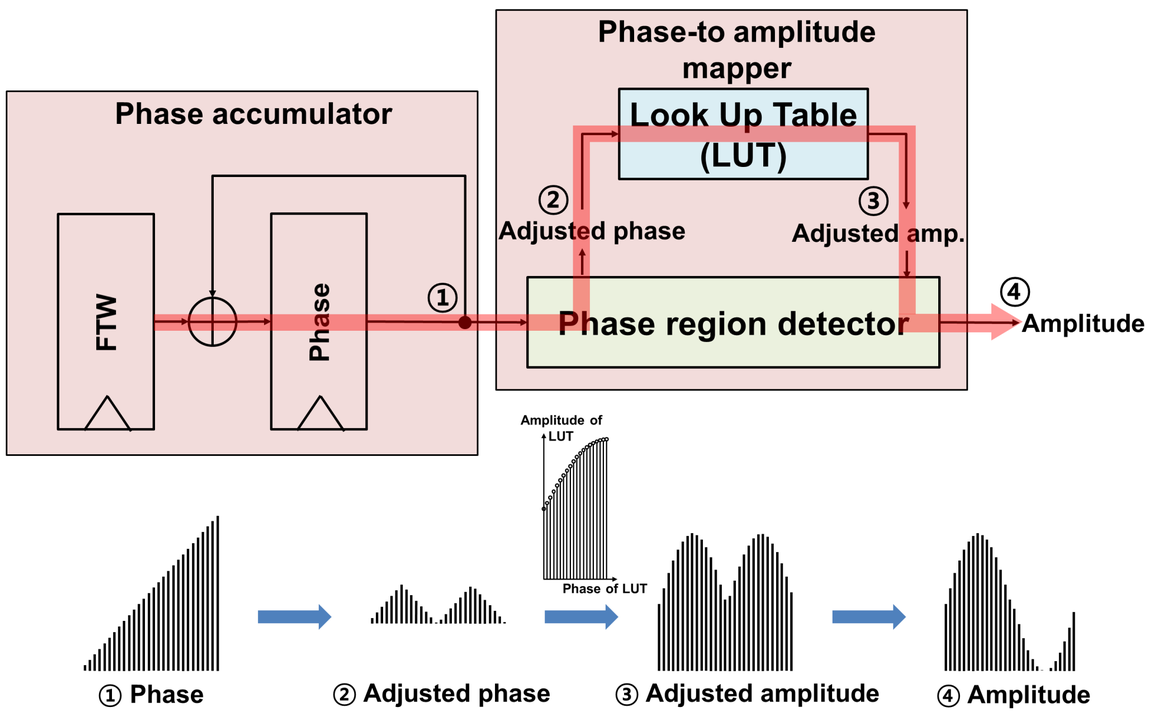
- Use periodicity and symmetry of sine wave
  → Memory size of LUT is reduced by a quarter.



❖ Using 1's complement in 3rd and 4th part

- Take 1's complement instead of 2's complement + add
  → Simpler computation

● Concept of Modeling



Output Frequency

$$f_{out} = \frac{L \times f_c}{2^M}$$

- f_{out}: Output frequency of DDFS
- L: Frequency tuning word (FTW) → Integer
- f_c: Sampling frequency (Clock frequency)
- M : Phase resolution

● Problems (Technical Issues)

❖ Overflow in transition region

- The phase of LUT is reduced by quarter. (M bit → M–2 bit)
  → The overflow occurs every quarter of phase.
- System is clock synchronized.
  → Solve the problem in advance

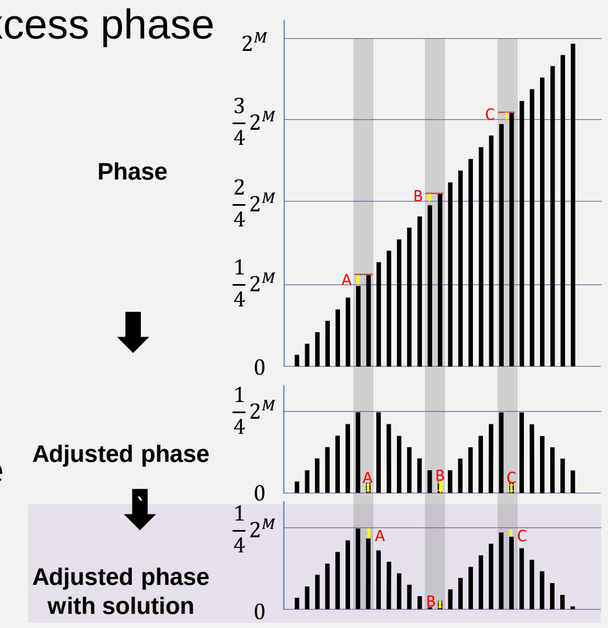
❖ Solution: Predict the overflow point

Concept

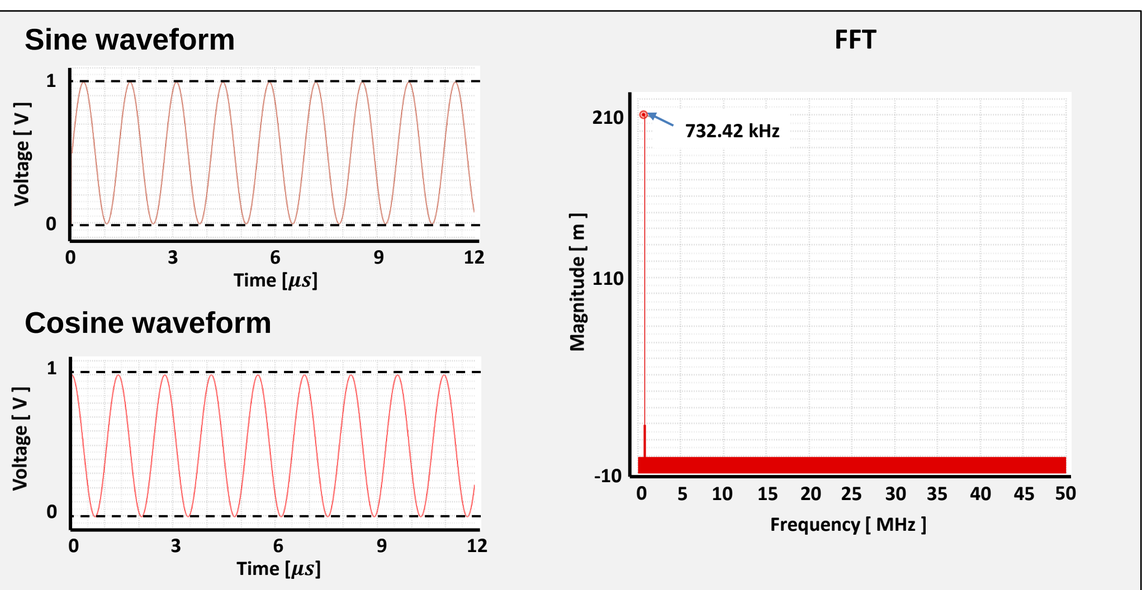
1. Predict the transition point.
2. Compensate for the excess phase

More details

- Calculate how far the next phase is from the boundary of quadrant.
- Substitute the value to the adjusted phase (B), or substrate the value from the max value of the adjusted phase(A, C).



● Results of modeling



Amplitude resolution: 12 bit

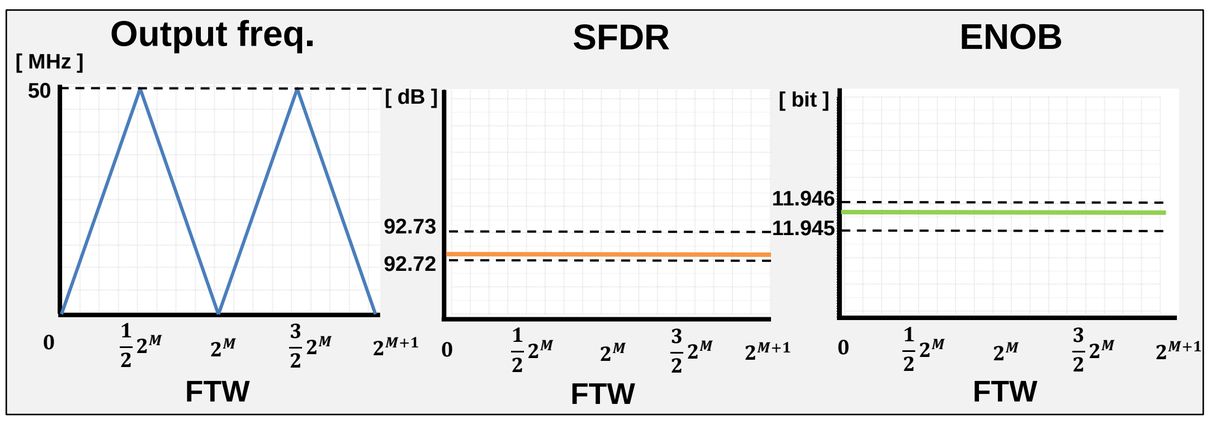
Clock frequency: 100 MHz

Phase resolution: 12 bit

Frequency tuning word(L): 31

- **Target frequency** $f_{target} = \frac{L \times f_c}{2^M} = \frac{31 \times 100 \times 10^6}{2^{12}} = 756.84\ kHz$
- **Output frequency** $f_{out} = 732.42 kHz$
- **Error rate** $Error = 3.27\%$

➡ **Error is created by quantization error.**



- FTW(Frequency tuning word) can be infinitely increased.
- Output frequency is limited to under the half of sampling frequency. (50 MHz)
- Output frequencies are folded in region ($\frac{M}{2} \leq L < M$), and the phase of sine waves will be flipped in folded frequency region.
- ENOB & SFDR are almost constant at all output frequencies.

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