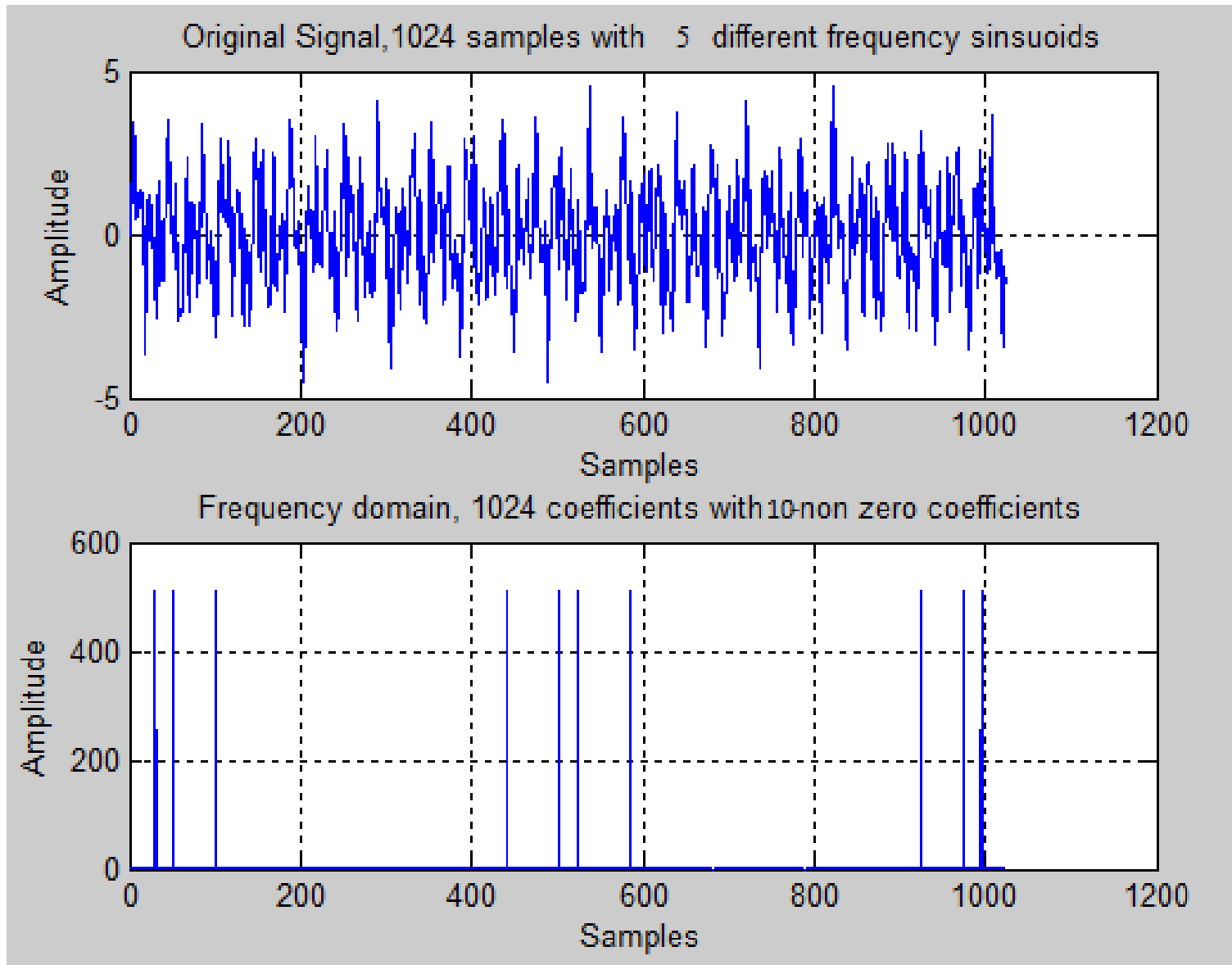


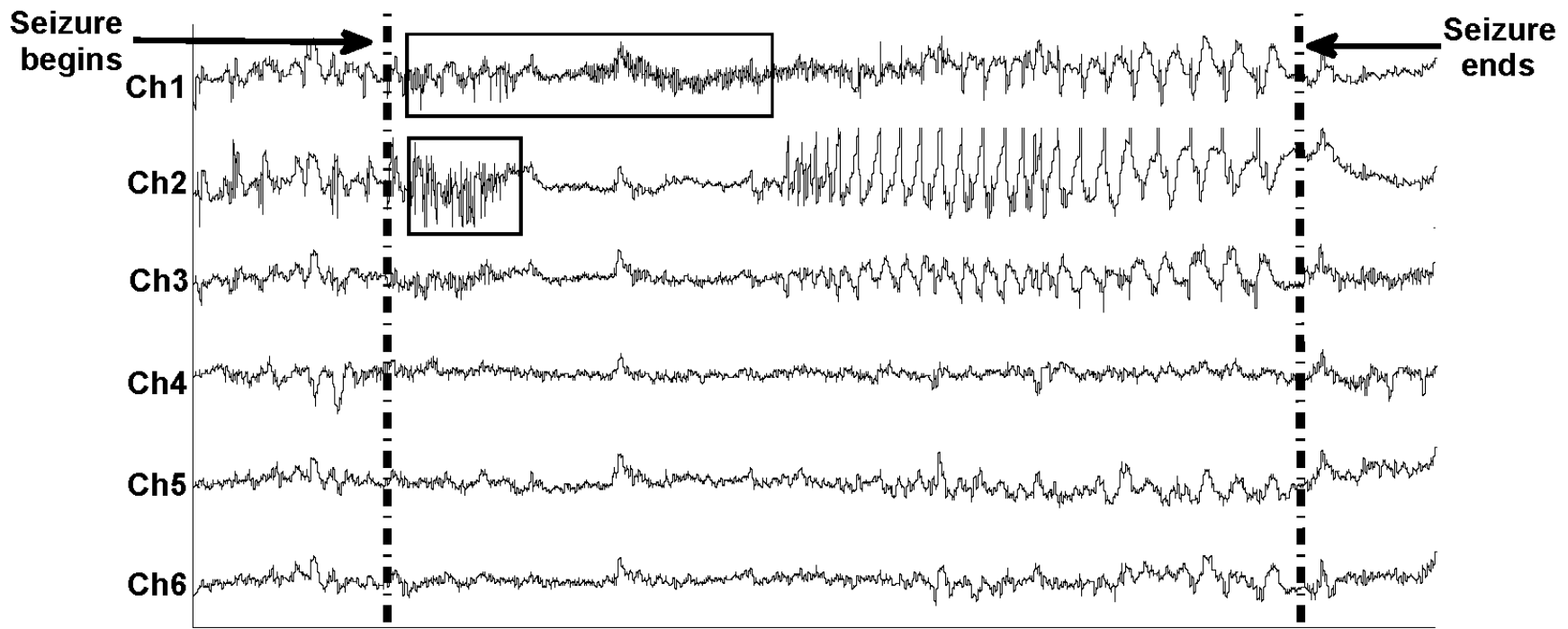
FFT Application Examples and Implementation

FFT Example 1: Signal Sparsity in time Frequency Domain



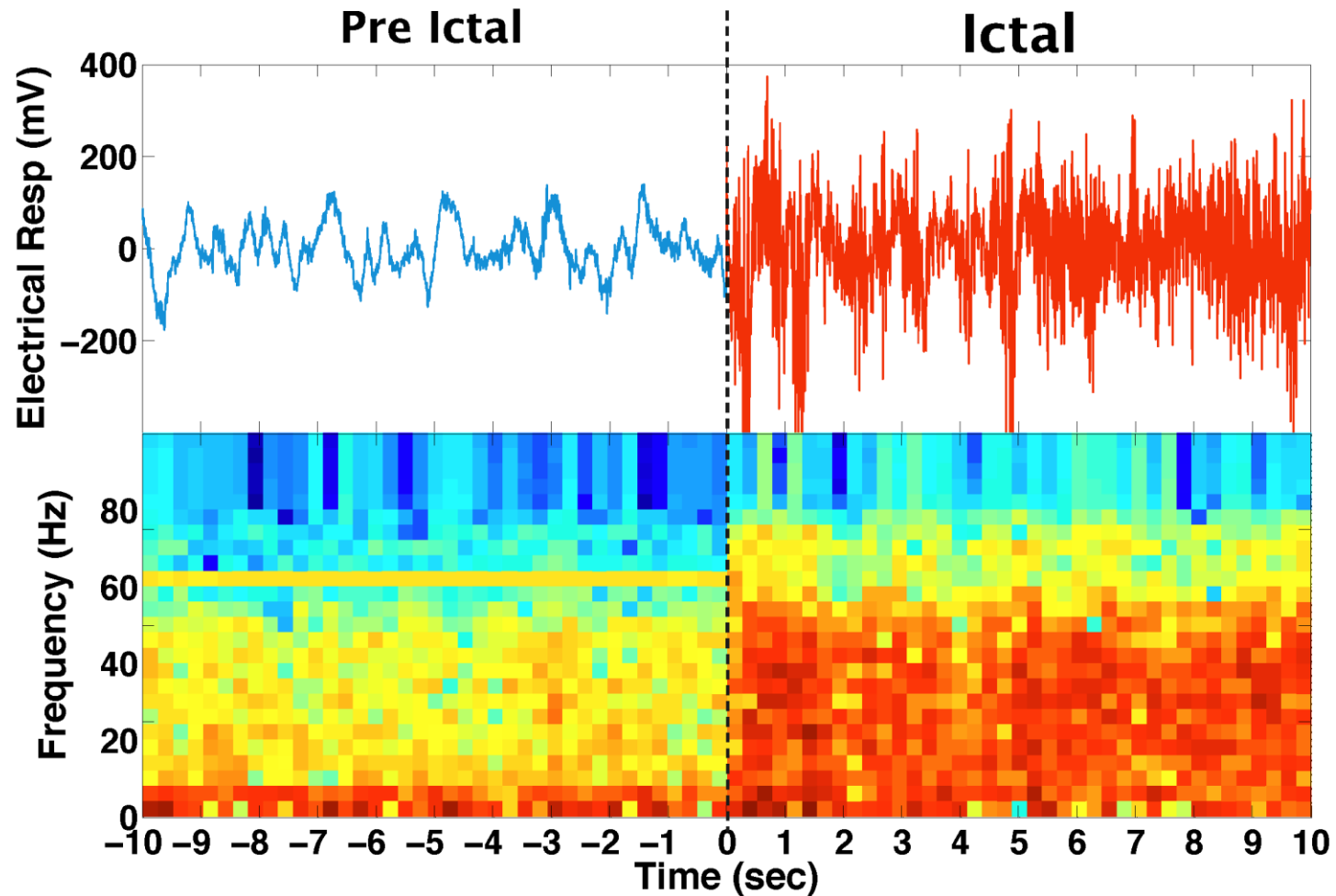
FFT Example 2: Seizure Detection Problem

- Electrical signals can be detected by EEG signals before or just at the start of clinical symptoms
 - The ability to detect can be used to warn the patient or alert caregiver



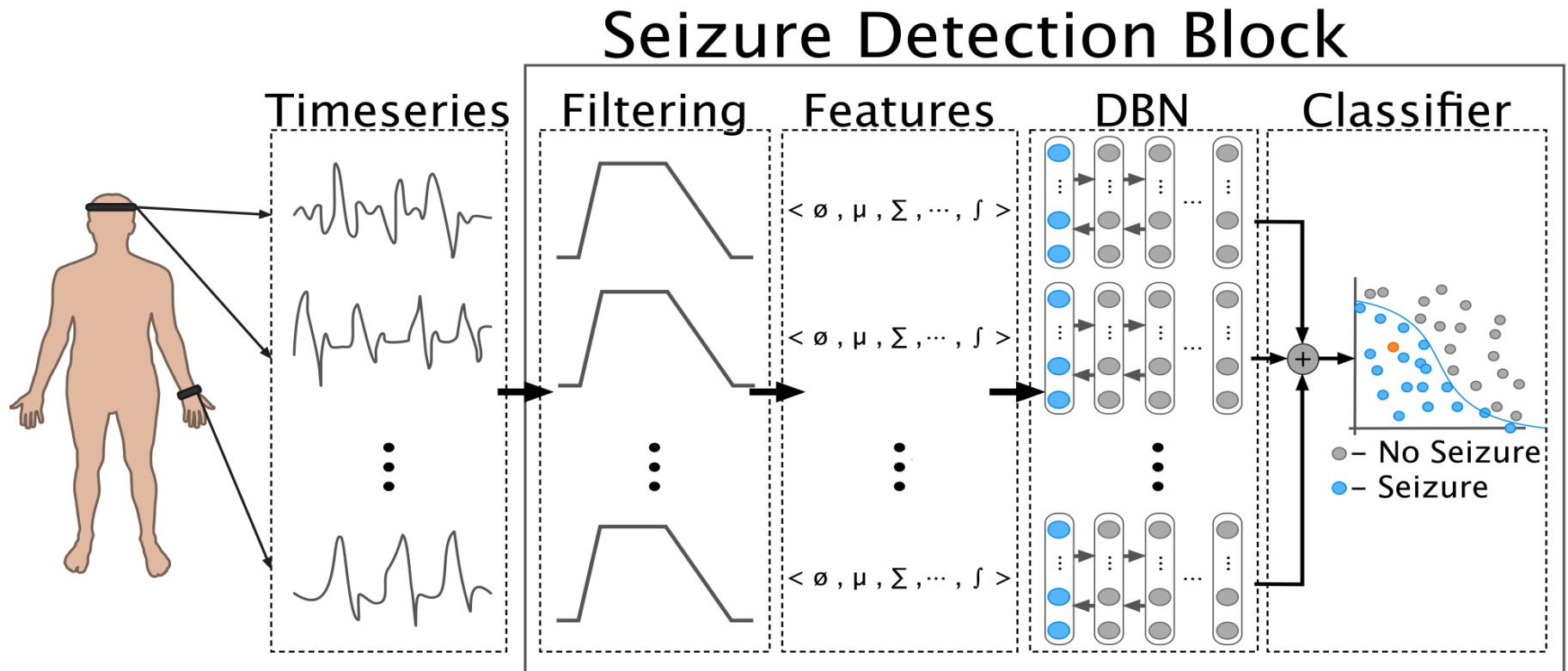
FFT Example 2: For Seizure, Frequency and Time domain analysis

- “We [doctors] detect seizures by looking at the evolution of frequency and amplitude in EEG” Dr. Jennifer Hopp, Epilepsy Center, UMMC.



A wearable solution for Multi-physiological signal processing

- Use FFT and filtering



FFT N-point implementation from FFT-2

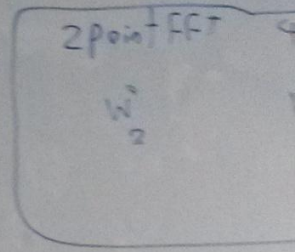
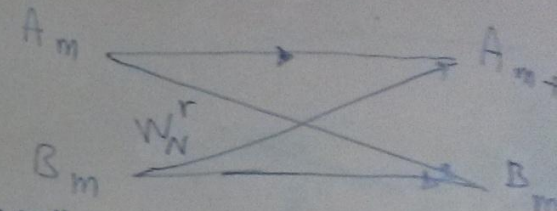
• FFT N where N is Power of 2.

- First calculate the Twiddle factors for half of N ($\frac{N}{2}$) \rightarrow

- Construct the diagram of FFT N

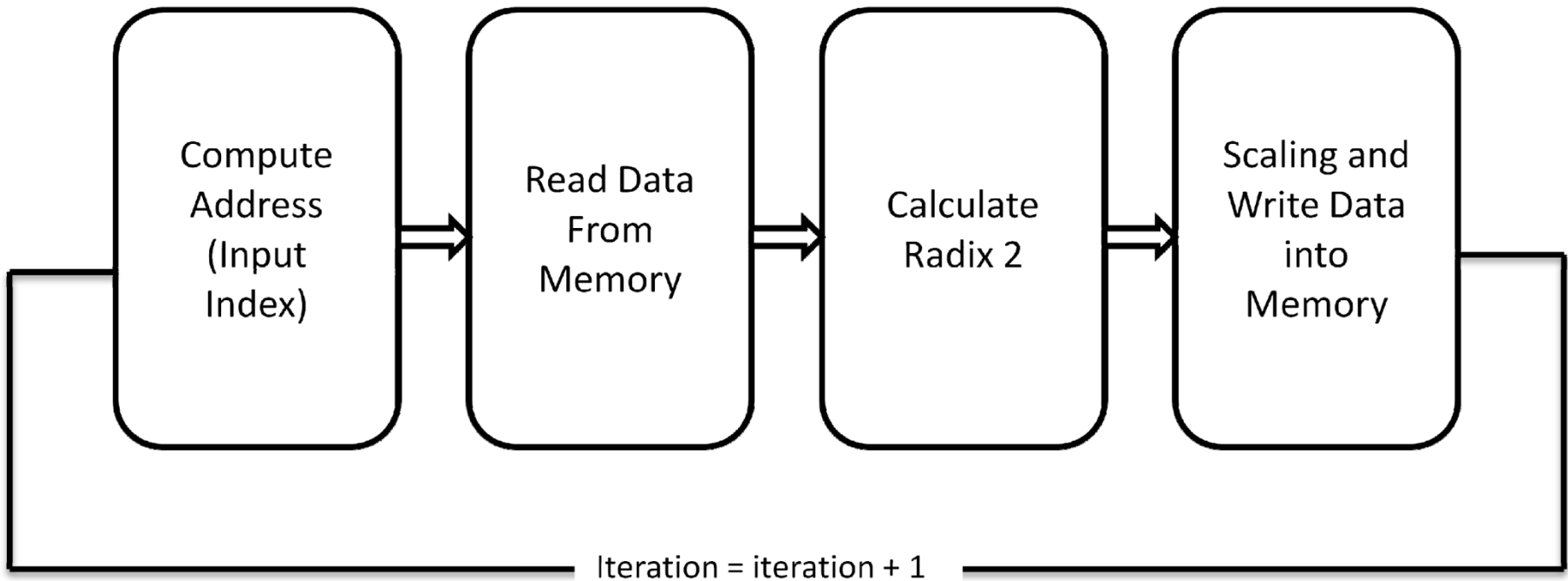
- Construct a 2-point FFT

- Build the FFT N using the 2-point FFT and diagram



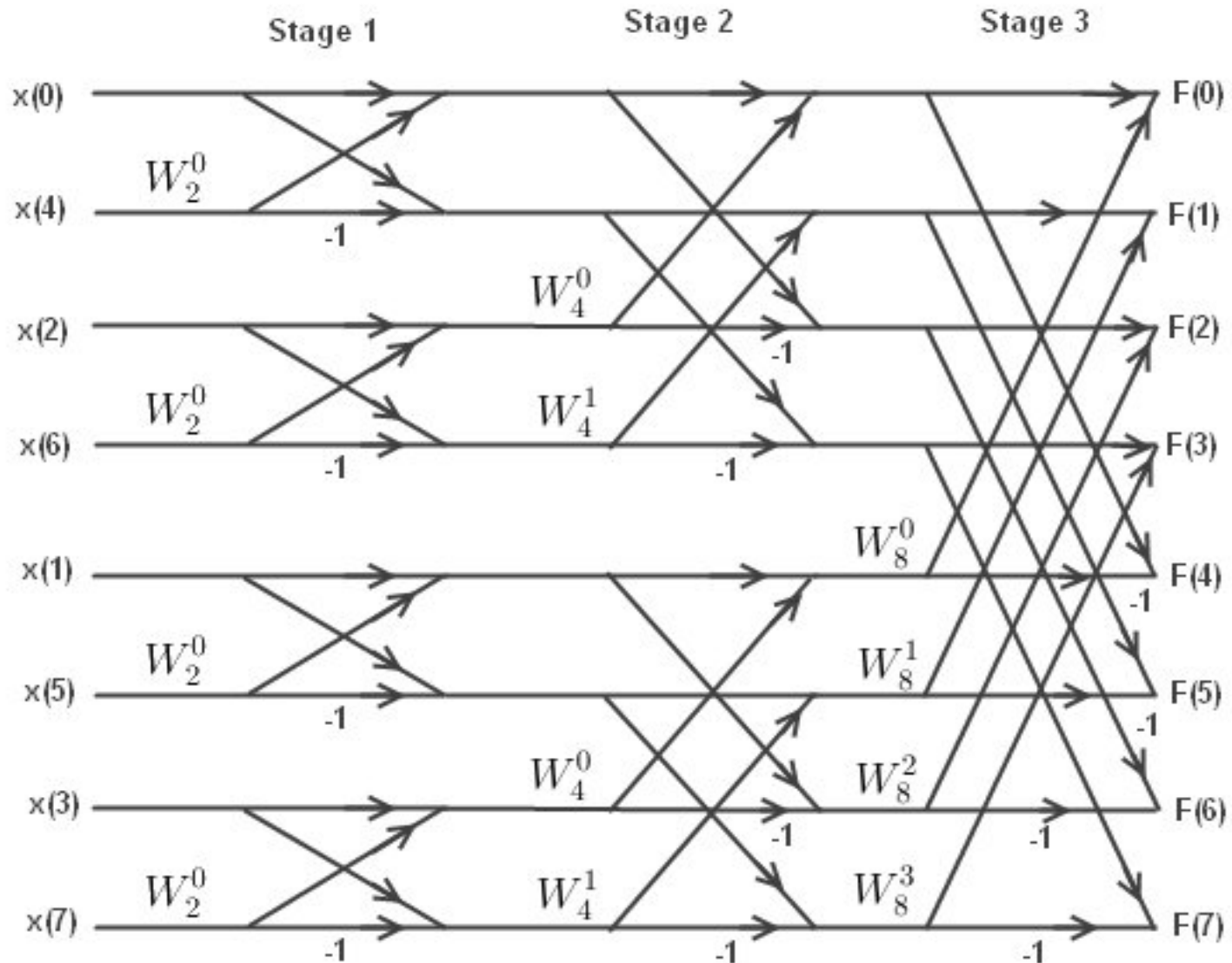
- 1) There are $\log N$ stages
- 2) There are $\frac{N}{2}$ of 2point FFT per stage.
- 3) The order of inputs are in bit reverse
- 4) For Twiddle factors: It shuffles between 2 ^(stage-1) samples, where * sta

FFT-N Calculation from FFT-2 (Radix-2)

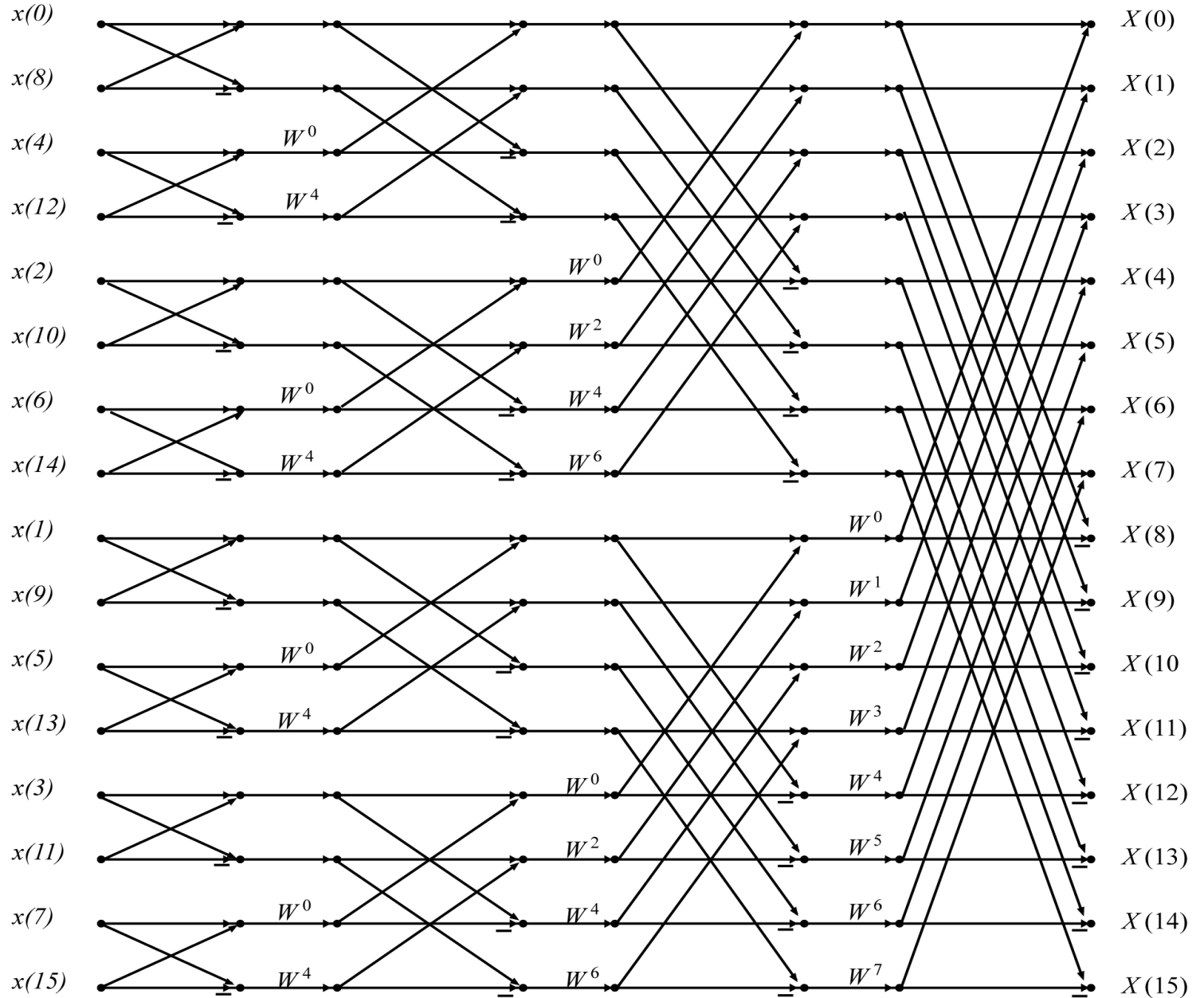


FFT 8-Point

An 8 Input Butterfly. Note, you double a 4 input butterfly, extend output lines, then connect the upper and lower butterflies together with diagonal lines.



FFT 16-Point



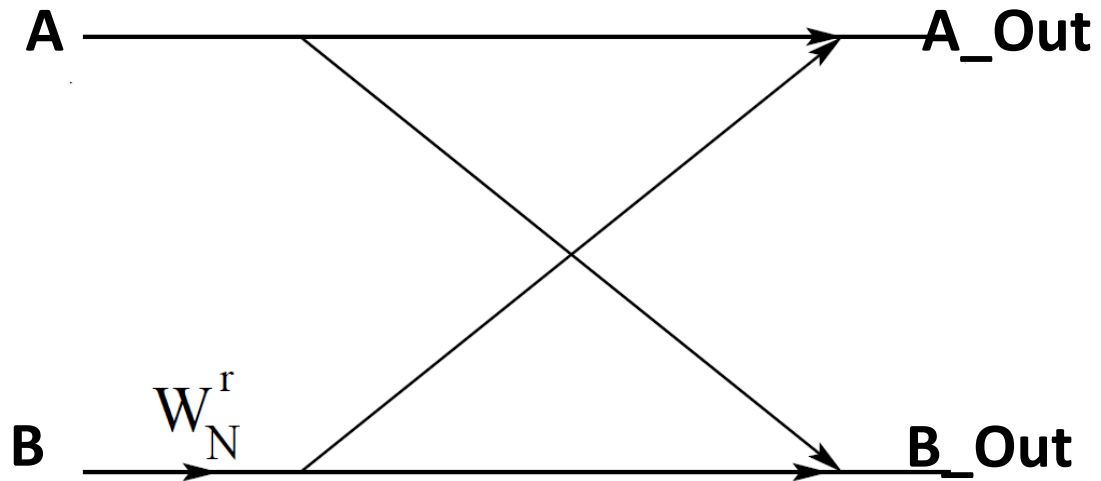
Twiddle factor Computation in Matlab

- Twiddle factor calculation in Matlab:
- Ex: $N=8$,
 - $W_0 = \exp(-2 * \pi * 0 * i / N) = 1$
 - $w_1 = \exp(-2 * \pi * 1 * i / N)$
 -
 - $W_7 = \exp(-2 * \pi * 7 * i / N)$

Radix-2 Butterfly Implementation

$$A_Out = A + W * B$$

$$B_Out = A - W * B$$



Where $A = A_r + iA_i$, $B = B_r + iB_i$, $W = W_r + iW_i$

So, $A_{out} = (A_r + W_r B_r - W_i B_i) + (B_r + W_r B_i + W_i B_r);$

$B_{out} = (A_r - W_r B_r + W_i B_i) + (B_r - W_r B_i - W_i B_r);$

FFT inputs bit reversal and memory addressing

- Bit reversal inputs example to FFT 8-point diagram
 - 0 = 000 reversed \rightarrow 000 = 0
 - 1 = 001 reversed \rightarrow 100 = 4
 - 2 = 010 reversed \rightarrow 010 = 2
 - 3 = 011 reversed \rightarrow 110 = 6
 - 4 = 100 reversed \rightarrow 001 = 1
 - 5 = 101 reversed \rightarrow 101 = 5
 - 6 = 110 reversed \rightarrow 011 = 3

- Refer to for FFT-8 example (very useful) in slides:
http://www.csee.umbc.edu/~tinoosh/cmpe691/slides/osattari_ms.pdf

FFT Memory storage requirements for serial implementation

Memory Requirement.

① BlockRAM: IF overwriting Per stage

For \underline{FFT}_N , you need N entries for Memory

For 16-bit Real and Imag $\Rightarrow N \times 32$ bit Mem

$$\log_2 16 = 4 \text{ stages}$$

$$\text{Per stage} = \frac{16}{2} = 8$$

FFT Twiddle factor Memory

Memory Requirement
(2) ROM/LUT for W factors

For FFT N : $e^{-j2\pi k \frac{N}{2}}$ $\rightarrow k$ is $0 \dots \frac{N}{2}$ $\frac{N}{2}$ W factor

- No. of entries:

FFT N : we need $\frac{N}{2}$ of real + $\frac{N}{2}$ of imag numbers.

- For W integer bits: $-1 < W < 1 \Rightarrow 2$ bits inter-

More details for FFT

- For more details refer to these documents:
- http://www.csee.umbc.edu/~tinoosh/cmpe691/slides/osattari_ms.pdf
- <http://www.csee.umbc.edu/~tinoosh/cmpe691/slides/Handout.fft1.diagrams.pdf>
- And FFT example from the book in the slides