

SOLUTIONS TO CHAPTER 2

Background

2.1 The DFT of a sequence $x(n)$ of length N may be expressed in matrix form as follows

$$\mathbf{X} = \mathbf{W}\mathbf{x}$$

where $\mathbf{x} = [x(0), x(1), \dots, x(N-1)]^T$ is a vector containing the signal values and \mathbf{X} is a vector containing the DFT coefficients $\mathcal{X}(k)$.

- (a) Find the matrix \mathbf{W} .
- (b) What properties does the matrix \mathbf{W} have?
- (c) What is the inverse of \mathbf{W} ?

Solution

(a) The DFT of a sequence $x(n)$ of length N is

$$\mathcal{X}(k) = \sum_{n=0}^{N-1} x(n)e^{-j\frac{2\pi}{N}nk} = \sum_{n=0}^{N-1} x(n)W_N^{nk}$$

where $W_N = e^{-j\frac{2\pi}{N}}$. If we define

$$\mathbf{w}_k^N = [1, W_N^k, W_N^{2k}, \dots, W_N^{(N-1)k}]$$

then $\mathcal{X}(k)$ is the inner product

$$\mathcal{X}(k) = \mathbf{w}_k^N \cdot \mathbf{x}$$

Arranging the DFT coefficients in a vector we have,

$$\mathbf{X} = \begin{bmatrix} \mathcal{X}(0) \\ \mathcal{X}(1) \\ \vdots \\ \mathcal{X}(N-1) \end{bmatrix} = \begin{bmatrix} \mathbf{w}_0^N \cdot \mathbf{x} \\ \mathbf{w}_1^N \cdot \mathbf{x} \\ \vdots \\ \mathbf{w}_{N-1}^N \cdot \mathbf{x} \end{bmatrix} = \mathbf{W}\mathbf{x}$$

where

$$\mathbf{W} = \begin{bmatrix} \mathbf{w}_0^N \\ \mathbf{w}_1^N \\ \vdots \\ \mathbf{w}_{N-1}^N \end{bmatrix} = \begin{bmatrix} 1 & 1 & 1 & \cdots & 1 \\ 1 & W_N & W_N^2 & \cdots & W_N^{N-1} \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 1 & W_N^{N-1} & W_N^{2(N-1)} & \cdots & W_N^{(N-1)N} \end{bmatrix}$$

(b) The matrix \mathbf{W} is symmetric and nonsingular. In addition, due to the orthogonality of the complex exponentials,

$$\mathbf{w}_k^N \cdot \mathbf{w}_l^N = \sum_{n=0}^{N-1} e^{-j\frac{2\pi}{N}(k-n)} = \begin{cases} N & : k = l \\ 0 & : k \neq l \end{cases}$$

It follows that \mathbf{W} is orthogonal.

(c) Due to the orthogonality of \mathbf{W} , the inverse is

$$\mathbf{W}^{-1} = \frac{1}{N} \mathbf{W}^H$$

Solution Manual For Statistical Digital Signal Processing

Chong-Yung Chi, Chih-Chun Feng, Chii-Horng Chen, Ching-Yung Chen

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