

# Worksheet 16

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## To accompany Chapter 6.3 The Inverse Z-Transform

### Colophon

This worksheet can be downloaded as a [PDF file](#). We will step through this worksheet in class.

An annotatable copy of the notes for this presentation will be distributed before the second class meeting as **Worksheet 16** in the **Week 9: Classroom Activities** section of the Canvas site. I will also distribute a copy to your personal **Worksheets** section of the **OneNote Class Notebook** so that you can add your own notes using OneNote.

You are expected to have at least watched the video presentation of [Chapter 6.3](#) of the [notes](#) before coming to class. If you haven't watch it afterwards!

After class, the lecture recording and the annotated version of the worksheets will be made available through Canvas.

### Agenda

- Inverse Z-Transform
- Examples using PFE
- Examples using Long Division
- Analysis in MATLAB

# The Inverse Z-Transform

The inverse Z-Transform enables us to extract a sequence  $f[n]$  from  $F(z)$ . It can be found by any of the following methods:

- Partial fraction expansion
- The inversion integral
- Long division of polynomials

## Partial fraction expansion

We expand  $F(z)$  into a summation of terms whose inverse is known. These terms have the form:

$$k, \frac{r_1 z}{z - p_1}, \frac{r_1 z}{(z - p_1)^2}, \frac{r_3 z}{z - p_2}, \dots$$

where  $k$  is a constant, and  $r_i$  and  $p_i$  represent the residues and poles respectively, and can be real or complex<sup>1</sup>.

### Notes

1. If complex, the poles and residues will be in complex conjugate pairs

$$\frac{r_i z}{z - p_i} + \frac{r_i^* z}{z - p_i^*}$$

## Step 1: Make Fractions Proper

- Before we expand  $F(z)$  into partial fraction expansions, we must first express it as a *proper* rational function.
- This is done by expanding  $F(z)/z$  instead of  $F(z)$
- That is we expand

$$\frac{F(z)}{z} = \frac{k}{z} + \frac{r_1}{z - p_1} + \frac{r_2}{z - p_2} + \dots$$

## Step 2: Find residues

- Find residues from

$$r_k = \lim_{z \rightarrow p_k} (z - p_k) \frac{F(z)}{z} = (z - p_k) \frac{F(z)}{z} \Big|_{z=p_k}$$

## Step 3: Map back to transform tables form

- Rewrite  $F(z)/z$ :

$$z \frac{F(z)}{z} = F(z) = k + \frac{r_1 z}{s - p_1} + \frac{r_2 z}{s - p_2} + \dots$$

## Example 1

Karris Example 9.4: use the partial fraction expansion to compute the inverse z-transform of

$$F(z) = \frac{1}{(1 - 0.5z^{-1})(1 - 0.75z^{-1})(1 - z^{-1})}$$



## MATLAB solution

See [example1.mlx](#). (Also available as [example1.m](#).)

Uses MATLAB functions:

- `collect` – expands a polynomial
- `sym2poly` – converts a polynomial into a numeric polynomial (vector of coefficients in descending order of exponents)
- `residue` – calculates poles and zeros of a polynomial
- `ztrans` – symbolic z-transform
- `iztrans` – symbolic inverse ze-transform
- `stem` – plots sequence as a “lollipop” diagram

```
clear all
cd matlab
format compact
```

```
syms z n
```

The denominator of  $F(z)$

```
Dz = (z - 0.5)*(z - 0.75)*(z - 1);
```

Multiply the three factors of Dz to obtain a polynomial

```
Dz_poly = collect(Dz)
```

## Make into a rational polynomial

 $z^2$ 

```
num = [0, 1, 0, 0];
```

 $z^3 - 9/4z^2 - 13/8z - 3/8$ 

```
den = sym2poly(Dz_poly)
```

## Compute residues and poles

```
[r,p,k] = residue(num,den);
```

## Print results

- `fprintf` works like the c-language function

```
fprintf('\n')
fprintf('r1 = %4.2f\t', r(1)); fprintf('p1 = %4.2f\n', p(1));...
fprintf('r2 = %4.2f\t', r(2)); fprintf('p2 = %4.2f\n', p(2));...
fprintf('r3 = %4.2f\t', r(3)); fprintf('p3 = %4.2f\n', p(3));
```

## Symbolic proof

$$f[n] = 2\left(\frac{1}{2}\right)^n - 9\left(\frac{3}{4}\right)^n + 8$$

```
% z-transform
fn = 2*(1/2)^n-9*(3/4)^n + 8;
Fz = ztrans(fn)
```

```
% inverse z-transform
iztrans(Fz)
```

## Sequence

```
n = 0:15;
sequence = subs(fn,n);
stem(n,sequence)
title('Discrete Time Sequence f[n] = 2*(1/2)^n-9*(3/4)^n + 8');
ylabel('f[n]')
xlabel('Sequence number n')
```

## Example 2

Karris example 9.5: use the partial fraction expansion method to to compute the inverse z-transform of

$$F(z) = \frac{12z}{(z+1)(z-1)^2}$$



## MATLAB solution

See [example2.mlx](#). (Also available as [example2.m](#).)

Uses additional MATLAB functions:

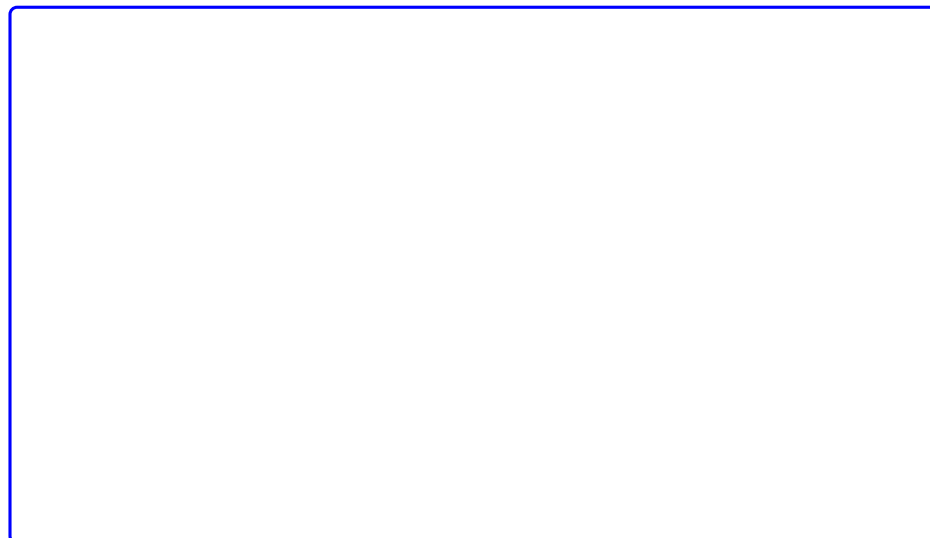
- `dimpulse` – computes and plots a sequence  $f[n]$  for any range of values of  $n$

[open example2](#)

## Example 3

Karris example 9.6: use the partial fraction expansion method to to compute the inverse z-transform of

$$F(z) = \frac{z+1}{(z-1)(z^2+2z+2)}$$



## MATLAB solution

See [example3.mlx](#). (Also available as [example3.m](#).)

[open](#) example3

## Inverse Z-Transform by the Inversion Integral

The inversion integral states that:

$$f[n] = \frac{1}{j2\pi} \oint_C F(z) z^{n-1} dz$$

where  $C$  is a closed curve that encloses all poles of the integrand.

This can (*apparently*) be solved by Cauchy's residue theorem!!

Fortunately (-:-), this is beyond the scope of this module!

See Karris Section 9.6.2 (pp 9-29—9-33) if you want to find out more.

## Inverse Z-Transform by the Long Division

To apply this method,  $F(z)$  must be a rational polynomial function, and the numerator and denominator must be polynomials arranged in descending powers of  $z$ .

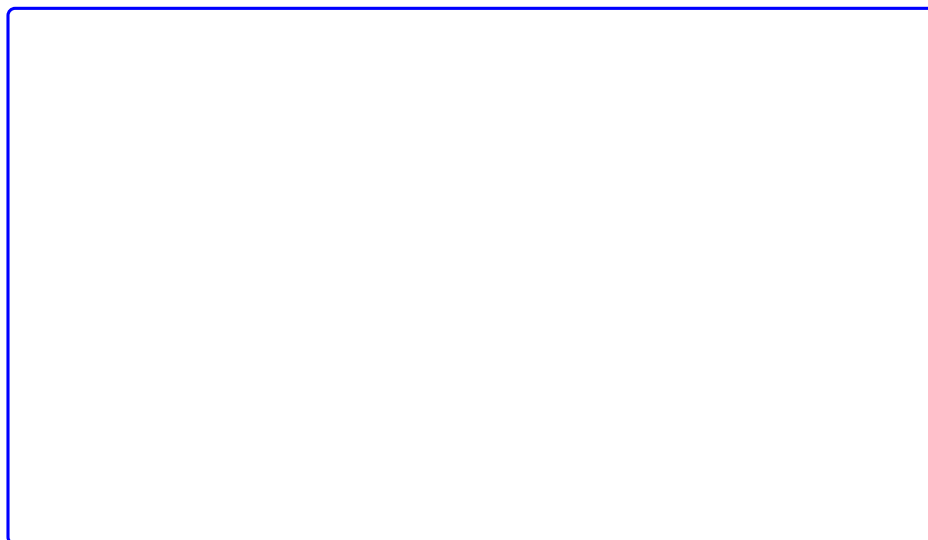
We will work through an example in class.

[Skip next slide in Pre-Lecture]

## Example 4

Karris example 9.9: use the long division method to determine  $f[n]$  for  $n = 0, 1,$  and  $2$ , given that

$$F(z) = \frac{1 + z^{-1} + 2z^{-2} + 3z^{-3}}{(1 - 0.25z^{-1})(1 - 0.5z^{-1})(1 - 0.75z^{-1})}$$



## MATLAB

See [example4.mlx](#). (also available as [example4.m](#).)

[open](#) example4

## Methods of Evaluation of the Inverse Z-Transform

### Partial Fraction Expansion

#### *Advantages*

- Most familiar.
- Can use MATLAB `residue` function.

#### *Disadvantages*

- Requires that  $F(z)$  is a proper rational function.

### Inversion Integral

#### *Advantage*

- Can be used whether  $F(z)$  is rational or not

#### *Disadvantages*

- Requires familiarity with the *Residues theorem* of complex variable analysis.

### Long Division

### *Advantages*

- Practical when only a small sequence of numbers is desired.
- Useful when z-transform has no closed-form solution.

### *Disadvantages*

- Can use MATLAB `impz` function to compute a large sequence of numbers.
- Requires that  $F(z)$  is a proper rational function.
- Division may be endless.

## Summary

- Inverse Z-Transform
- Examples using PFE
- Examples using Long Division
- Analysis in MATLAB

### *Coming Next*

- DT transfer functions, continuous system equivalents, and modelling DT systems in Matlab and Simulink.

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