| **Advanced Engineering Mathematics** | | **Homework Five** |
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| | Fourier Series : Arbitrary Domains, Complex Representation, Resonant Forcing | |
| Text: 11.3-11.4 | Lecture Notes : 9-10 | Lecture Slides: N/A |

Quote of Homework Five

**Carlos Castaneda**: I had not been using my eyes. That was true, yet I was very sure he had said to feel the difference. I brought that point up, but he argued that one can feel with the eyes, when the eyes are not looking right into things.

Carlos Castaneda - The Teachings of Don Juan: A Yaqui Way of Knowledge (1968)

## 1. Fourier Series : Nonstandard Domain

Let $f(x) = x^2$ for $x \in (0, 2\pi)$ be such that $f(x + 2\pi) = f(x)$.

1.1. **Graphing.** Sketch $f$ on $(-4\pi, 4\pi)$.

1.2. **Symmetry.** Is the function even, odd or neither?

1.3. **Integrations.** Determine the Fourier coefficients $a_0, a_n, b_n$ of $f$.

1.4. **Truncation.** Using `http://www.tutor-homework.com/grapher.html`, or any other graphing tool, graph the first five terms of your Fourier Series Representation of $f$.

## 2. Fourier Series : Nonstandard Period

Let $f(x) = \begin{cases} 0, & -2 < x < 0 \\ x, & 0 < x < 2 \end{cases}$ be such that $f(x+4) = f(x)$.

2.1. **Graphing.** Sketch $f$ on $(-4, 4)$.

2.2. **Symmetry.** Is the function even, odd or neither?

2.3. **Integrations.** Determine the Fourier coefficients $a_0, a_n, b_n$ of $f$.

2.4. **Truncation.** Using `http://www.tutor-homework.com/grapher.html`, or any other graphing tool, graph the first five terms of your Fourier Series Representation of $f$.

## 3. Fourier Series : Periodic Extension

Let $f(x) = \begin{cases} \dfrac{2k}{L}x, & 0 < x \leq \frac{L}{2} \\ \\ \frac{2k}{L}(L-x), & \frac{L}{2} < x < L \end{cases}$.

3.1. **Graphing - I.** Sketch a graph $f$ on $[-2L, 2L]$.

3.2. **Graphing - II.** Sketch a graph $f^*$, the even periodic extension of $f$, on $[-2L, 2L]$.

3.3. **Fourier Series.** Calculate the Fourier cosine series for the half-range expansion of $f$.

## 4. Complex Fourier Series

4.1. **Orthogonality Results.** Show that $\left\langle e^{inx}, e^{-imx} \right\rangle = 2\pi\delta_{nm}$ where $n, m \in \mathbb{Z}$, where $\langle f, g\rangle = \displaystyle\int_{-\pi}^{\pi} f(x)g(x)dx$.

4.2. **Fourier Coefficients.** Using the previous orthogonality relation find the Fourier coefficients, $c_n$, for the complex Fourier series, $f(x) = \displaystyle\sum_{n=-\infty}^{\infty} c_n e^{inx}$.

4.3. **Complex Fourier Series Representation.** Find the complex Fourier coefficients for $f(x) = x^2,\ -\pi < x < \pi,\ f(x + 2\pi) = f(x)$.

4.4. **Conversion to Real Fourier Series.** Using the complex Fourier series representation of $f$ recover its associated real Fourier series.

## 5. Periodic Forcing of Simple Harmonic Oscillators

Consider the ODE, which is commonly used to model forced simple harmonic oscillation,

$$y'' + 9y = f(t), \tag{5.1}$$

$$f(t) = |t|, \quad -\pi \le t < \pi, \quad f(t+2\pi) = f(t). \tag{5.2}$$

Since the forcing function (5.2) is a periodic function we can study (5.1) by expressing $f(t)$ as a Fourier series. [1] [2]

5.1. **Fourier Series Representation.** Express $f(t)$ as a real Fourier series.

5.2. **Method of Undetermined Coefficients.** The solution to the homogeneous problem associated with (5.1) is $y_h(t) = c_1\cos(3t) + c_2\sin(3t), \quad c_1, c_2 \in \mathbb{R}$. Knowing this, if you were to use the method of undetermined coefficients[3] then what would your choice for the particular solution, $y_p(t)$? DO NOT SOLVE FOR THE UNKNOWN CONSTANTS

5.3. **Resonant Modes.** What is the particular solution associated with the third Fourier mode of the forcing function?[4][5]

5.4. **Structural Changes.** What is the long term behavior of the solution to (5.1) subject to (5.2)? What if the ODE had the form $y'' + 4y = f(t)$?

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[1] The advantage of expressing $f(t)$ as a Fourier series is its validity for any time $t$. An alternative approach have been to construct a solution over each interval $n\pi < t < (n+1)\pi$ and then piece together the final solution assuming that the solution and its first derivative is continuous at each $t = n\pi$.

[2] It is worth noting that this concepts are used by structural engineers, a sub-disciple of civil engineering, to study the effects of periodic forcing on buildings and bridges. In fact, this problem originate from a textbook on structural engineering.

[3] This is also known as the method of the 'lucky guess' in your differential equations text.

[4] Each term in a Fourier series is called a mode. The first mode is sometimes called the fundamental mode. The rest of the modes, called *harmonics* in acoustics, are just referenced by number. The third Fourier mode would be the third term of Fourier summation

[5] Note: If you reuse the results of problem 3 from this assignment then you should consider the sixth-mode not the third. If you evaluate the Fourier series representation straight-up in terms of the $2\pi$-periodic formula then the resonant mode turns out to be the third-mode.