Module 8 - How Do We Get Frequency Spectra from MR Signal?
Instructor's Manual

Suggested Prior Modules

None. This module provides an easy introduction to the Fourier Transform and the frequency information it can provide to help us analyze time-dependent signals. The very last section shows the use of the Fourier Transform to analyze NMR FID data and give the desired frequency spectrum for NMR spectroscopy. For that reason, students would ideally have seen what the raw, time-domain FID data looks like.

Particular prior knowledge from previous math or science courses that students are expected to have familiarity with:

- Sinusoidal functions written in the form: $s(t)=A\sin(2\pi ft+\phi)$
- Definitions of amplitude, period, and frequency

Suggested Use:

The instructions below are suggestions to help students engage with the material in class and were implementations of the materials that the developers used in their classes. However, all sections, activities, and questions in this module can successfully be done asynchronously online to serve as a pre-reading assignment in preparation for class or lab. This module requires a lot of sketching, so we highly suggest students answer the questions on paper rather than electronically.

Whether students are completing the module at home or in class, each pair of students or in-class group will need access to a smartphone and/or tablet that can install the free phyphox app that is used in this module to look at the Fourier transform of various types of audio signals.

Expected Learning Outcomes

At the end of this module, students should be able to...

1. *Identify what information the Fourier transform provides about a periodic signal (Scientific Ability B7)*
2. *Use the provided equipment to acquire time-domain data and show the FFT (Scientific Ability D3)*
3. *Sketch the frequency spectra that correspond to a simple sinusoidal time-domain signal in either graphical or equation form (Scientific Ability A7)*

This material is based upon work supported by the National Science Foundation under award DUE-2120545. Making Nuclear Magnetic Resonance Resonate With Students: Integrating NMR Into the Undergraduate Science Curriculum,

Background Information

(10 minutes)

Suggested activity: Have students take turns reading aloud the text, along with the information in the margin. You can have the class do an open brainstorming session on the discussion questions. These open-ended questions serve as a good icebreaker to get students ready to engage with the rest of the material.

Observation Experiments: Looking at FFTs of Sinusoidal Time-Domain Signals

(10 minutes)

Suggested activity: Students can pair up with one person whistling (as this produces a nice pure tone) or running an online tone generator and the other running the Audio spectrum experiment on the phyphox app on a phone or tablet to record the data. The 'Spectrum' tab will show the Fourier transform and the 'Raw Data' tab will show the time-domain data. There will be a lot of background noise, so pairs may have to go find some quiet spots to perform their experiments. These experiments can also be done as a class if the instructor can project the phyphox app results so everyone can see them and then the guided inquiry questions can be completed in small groups.

Testing Experiment: Expanding Beyond Sinusoidal Functions

(30 minutes)

Suggested activity: This section is best done in small groups and most of the time is spent on students developing and performing an experiment using the provided equipment to test the given hypothesis. Ideally, students would use pure tone sound sources without many harmonics for these experiments. Along with whistles or tone generators, we have found resonator boxes and whirly tubes to be nice sound sources for these experiments.

Observation Experiment: Exploring the FFTs of Periodic Time-Domain Signals

(20 minutes)

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Suggested activity: The class can set up the observation experiment with a square waveform. This waveform can be selected on using the online tone generator and/or an option on most function generators. The student pairs can sketch the resulting time domain signal and FFT using the phyphox app. Pairs can then move on to looking at the Desmos calculator together to determine their judgment on the validity of the provided hypothesis.

What Information Does the Fourier Transform Provide?

(20 minutes)

Suggested activity: Have students take turns reading aloud the text, along with the information in the margin. You can have the class do a think-pair-share on the remaining guided inquiry questions.

Reflection Questions

(Any Remaining Time)

Suggested activity: In any remaining time, you can choose some or all of the questions as a small group or individual reflection activity. Often, these are good open questions that provide an opportunity for students to reflect on everything they have learned in this module. These questions can be completed outside of class as homework and used to assess students' comprehension of the material.

In the last 5 minutes of class: Give the students some time in class to assess themselves on the learning objectives using the provided rubric in the student worksheet that is found on the next page.

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Scientific Ability	Adequate	Needs improvement	Inadequate	Missing
Identify what information the Fourier transform provides about a periodic signal	Identifies the correct information that the Fourier transform provides about a periodic signal.	Identifies some correct information with minor errors or omissions.	The information described is irrelevant or inconsistent with the data.	No attempt is made to Identify information
Use the provided equipment to acquire time-domain data and show the FFT	All of the chosen measurements can be made, and all details about how they are done are provided and clear.	All of the chosen measurements can be made, but the details about how they are done are vague or incomplete.	All of the chosen measurements can be made, but no details are given about how it is done.	Could not use the equipment to acquire the desired data.
Sketch the frequency spectra that correspond to a simple sinusoidal time-domain signal in either graphical or equation form	Sketch contains all key items with correct labeling of all physical quantities, has consistent subscripts, and axes are drawn and labeled correctly.	Sketch has no incorrect information, but has either no or very few labels of given quantities. The majority of key features are drawn.	Sketch is drawn, but it is incomplete, or important information is missing, or it contains the wrong information, or coordinate axes are missing.	No sketch is made.

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