Experiment 4: Frequency Modulation

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Abstract
This experiment includes the simulation and implementation of both FM modulator and demodulator. The particular case of a sinusoidal message signal modulating a sinusoidal carrier will be studied in detail.

Keywords
Phase Modulation — Frequency Modulation — Phase-Locked Loop

Contents

Introduction

In Experiment 3, you designed and simulated an AM modulator for two cases, implemented two AM demodulators and tested them under noisy conditions. In this experiment, another widely used modulation technique will be introduced: Frequency Modulation (FM). As the amplitude of the sinusoidal carrier wave was modulated in AM, this time the instantaneous **frequency** of a sinusoidal carrier wave will be modified proportionally to the variation of amplitude of the message signal. You can also see this process as a voltage-controlled oscillation: as the voltage of the input varies, so does the sinusoidal frequency of the output. FM is widely used in commercial radio, spanning be RF band between 88MHz and 108MHz. In commercial radio, a regulatory body (the CRTC in Canada, the FCC in the United States) allocates 200KHz of bandwidth for each station, or channel.

A two-step process will allow you to become more familiar with FM:

- First, a frequency modulation system will be created and simulated using `Simulink`.
- Second, an FM demodulator based on a Phase Locked Loop (PLL) will be designed and simulated, using the previous modulator as the "signal source".

You will be required to change various system parameters and observe the consequences of the changes.

1. Background Reading

Frequency Modulation (FM), as well as Phase Modulation (PM), are types of Angle (Exponential) Modulation. These are covered in more detail in [**?**], pp. 166-169.Take a look at the theory behind Phase-Locked Loops (PLL), as in pp. 178-182 of [**?**].

2. Experiment

2.1 Designing and Simulating an FM Modulator

Based on the FM signal equation and the block diagram for an FM modulator that you have submitted with your lab preparation, build your model in `Simulink`. Follow similar procedures for input sources and output sinks to what you have used in previous experiments. In particular, do not forget the following details:

- The input to an FFT-based scope must be buffered, with a buffer size that is an integer multiple of the FFT size (could be the same size). It makes no sense to attempt to perform an FFT on a single sample, or buffer a smaller number of samples than the length of the FFT;

- A greater FFT length means a better resolution for the frequency domain representation of the signal (take 1024 points as a reasonable length). Frequencies which fall at an integer multiple of f_s/N will be resolved exactly. At this point you should be able to tell when the results are producing relevant information or not;

- All blocks that require a sampling frequency (or sampling rate) to be defined **must have** the same sampling frequency. You should preferably use 1/96000 as the sampling rate (that is, a 96KHz sampling frequency) throughout your simulation exercise;

- The frequency of a commercial FM carrier wave in practice is much higher than the one utilized in this experiment. Your favourite FM radio station operates between 88MHz and 108MHz over the air. Though we will use a lower carrier frequency in this experiment, feel free to explore on your own the limiatations (if any) of the simulation.

Build a `Simulink` block diagram for the FM modulator exactly like the one you presented in your lab preparation. Add a $2V_{pp}$, 750Hz sinusoid as input, 12000Hz as carrier and set 3600 Hz/V as sensitivity. Add time domain and frequency domain scopes to the output (similar to the ones you had in the AM experiment). Try to run it now. If it runs, great. Answer some of the questions in the answer sheet.

If it did not run, though, do not panic just yet; keep on reading.

Take a look at the FM equation you wrote, and try to re-work it. Bring some elements "into the integral" and see if it will simplify your block diagram. Pay particular attention to the time variable t on the equation. Do not despise the factor 2π on the constant k_f if you are working with ω (in *rad/s*).

As mentioned above, use as input signal a sine wave with amplitude 1.0 (this would mean a $2V_{pp}$ simulated signal) and frequency 750Hz. Build your modulator with a carrier frequency of 12000Hz and a sensitivity factor of 3600Hz/V (that's the k_f constant on [**?**]). Note how the blocks correspond to (and operate like) the FM equation from theory.

Everything going well, you should observe a time domain output signal similar to the one you drafted on your lab preparation sheet. In this lab you will concentrate on understanding what goes on in the frequency domain for a sine wave message modulating a sine wave carrier. Make sure your frequency domain display gives you a good picture.

When you are finished putting the simulation to work, move on to answer some questions on the separate answer sheet.

So your model should look like Figure 1 below. This is a *suggested* model. Your working model may differ from this one.

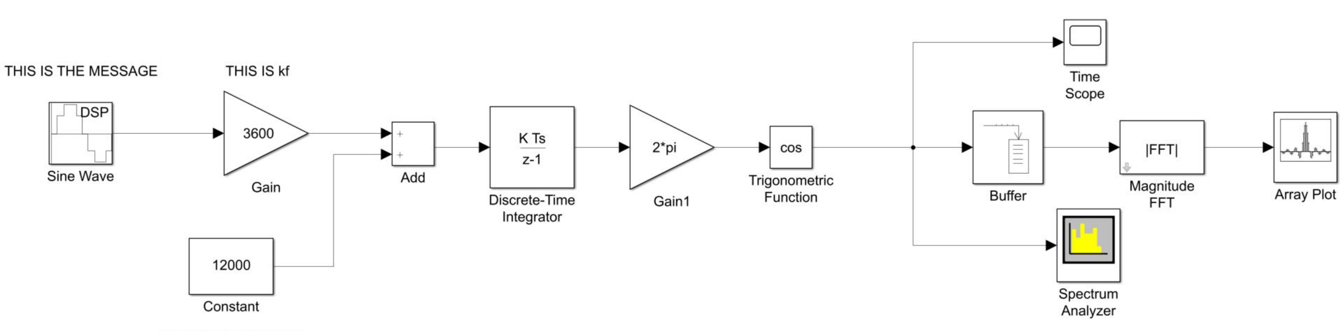

Figure 1. Suggested FM Modulator for Simulation

2.2 Designing and Simulating an FM Demodulator

Following the block diagram of the PLL-based FM demodulator you have drawn on your preparation sheet, build a new model in `Simulink`. The input signal for the demodulator simulation will be the FM-modulated signal from your modulator. Your demodulator should be made of a PLL and, if necessary, an output low-pass filter. The PLL, as you have drawn on your lab preparation, is made of a voltage-controlled oscillator, a multiplier and a low-pass filter. It is not always necessary to have a second filter after the PLL. You may be able to avoid the use of a second filter by using a loop filter with a sharper roll-off at the cutoff frequency of interest.

You will need to make a change to the VCO on the feedback path, by setting the trigonometric function block to `sine`. For those who were attentive to this detail while reviewing the theory, the PLL design calls for a 90 degree shift between the incoming FM-modulated signal and the signal output from the VCO on the feedback loop. Check out [**?**], p. 178 and 179.

To make your life easier, you can create a "subsystem" with your modulator (VCO), and utilize this new block to implement your demodulator. To do this, select the blocks on your model that implement the VCO, right-click on it and select `create subsystem`. The constants and gains that you have to adjust for the VCO are the same as the ones used on the modulator (the VCO **is** a frequency modulator). The forward path filter will be designed using the FDA-tool block. Make the filter a low-pass FIR design using `windowing` (this is set by the drop-down menu found beside `FIR` on the low left corner of the FDA-tool). Set the order to 30 or higher, select a Kaiser window and check the `scale passband` option. The cutoff frequency is the frequency of your **modulating** signal.

Run your modulator-demodulator system. If your output is still not looking right, try increasing the amplitude of your **message** signal to $2V_p$ and work with a higher message signal frequency such as, say, 3KHz. Your system should resemble Figure 2 below.

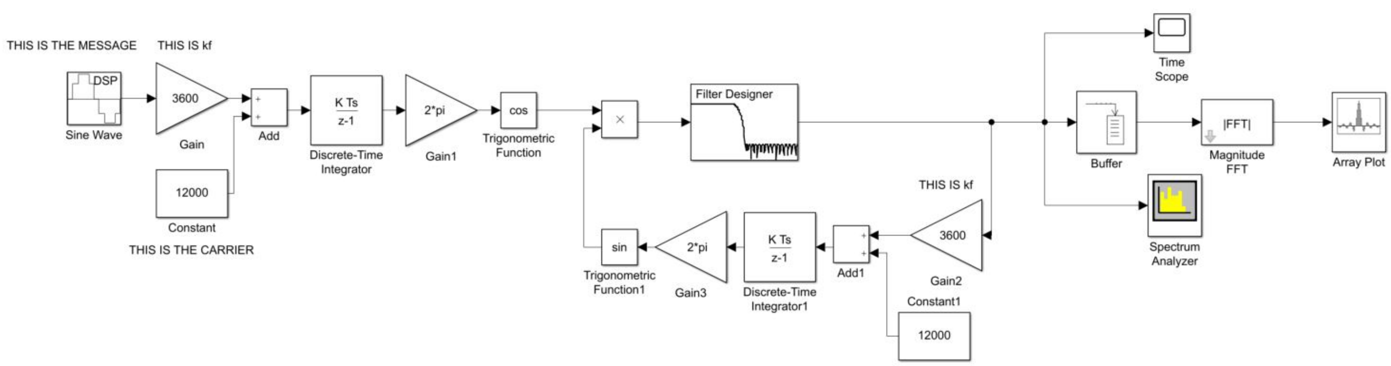

Figure 2. Suggested FM DEmodulator for Simulation

After you made it work, move to the answer sheet to answer some questions.

3. Two Steps Further

This is NOT mandatory for the experiment. If you feel adventurous, you can try to use the audio input from the computer and bring music into `Simulink`, or play it from a file. Just like you did with a sinusoid, you can try to use your complete system to see if you can modulate and demodulate your signal and recover it at the output of the demodulator. Remember, you will need as input an analog signal sampled at 96KHz. At the receiver (demodulator) end, you could either save the demodulated signal into a file (this would be a sampled signal at 96KHz), or try to play it through the loudspeaker.

Also, if you have access to an older FM radio – one with a rotating dial and a moving needle – this will likely assist you in better picturing the FM spectrum and how the radio stations transmit their signal. In the experiment today we explored a straight-forward *mono* modulation and demodulation. By *mono* it is meant one channel of audio rather than two (which would be *stereo*).

4. Accomplishments

In this experiment, you were required to design and simulate an FM modulator and demodulator. As a result, it is hoped that you became familiar with the theory behind Angle Modulation, and with some practical details pertaining to the modulation and demodulation of a baseband signal. All of these concepts are widely used in the study of communication systems.

Acknowledgments

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References