Experiment 3: 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. At the end of the experiment, students are encouraged to pair with neighbouring groups to implement a full modulation-demodulation system, using music from an mp3 player/phone and listening to the demodulated signal with speakers.

Keywords
Phase Modulation — Frequency Modulation — Phase-Locked Loop

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Introduction

In Experiment 2, you designed, simulated and built an AM modulator, and hopefully had the opportunity also to see how to demodulate an AM signal. 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 three-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".
- Third, an FM modulator and PLL-based demodulator will be implemented on a DSP platform running in real-time. The input (message) signal to the modulator will come from the signal generator.

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 [1], pp. 166-169.Take a look at the theory behind Phase-Locked Loops (PLL), as in pp. 178-182 of [1].

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 period) to be defined **must have** the same sampling frequency. Since the CODEC on the board uses a 48KHz sampling frequency, you should preferably use this number 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. You must keep in mind, however, that in the lab we are operating within the audio CODEC range. The carrier frequencies for this experiment will be compatible with the hardware you are using.

Build a `Simulink` block diagram for the FM modulator exactly like the one you presented in your lab preparation. Add a sinusoid as input and time domain and frequency domain scopes to the output. 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 put your hand up just yet.

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. Do not despise the factor 2π on the constant k_f if you are working with ω (in *rad/s*).

Use as input signal a sine wave with amplitude 1.0 (this would mean a $2V_{pp}$ simulated signal) and frequency 1200Hz. Build your modulator with a carrier frequency of 9000Hz and a sensitivity factor of 3600Hz/V (that's the k_f constant on [2]).

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 sinusoidal 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. For instance, you should try to use a `Discrete-Time Integrator` rather than the digital filter shown below (search for that block within `Simulink`.

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 [1], p. 178 and 179.

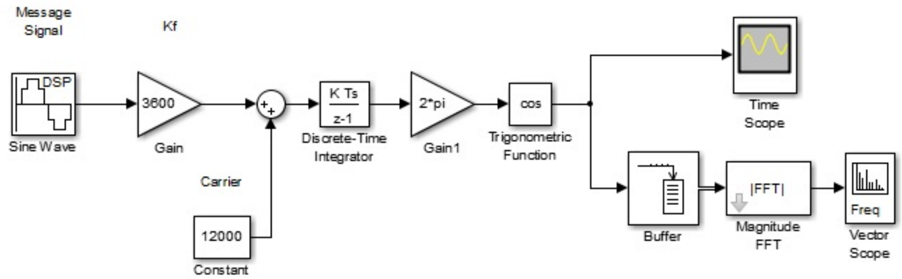

Figure 1. Suggested FM Modulator for Simulation

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, 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 $2V_p$. Your system should resemble Figure 2 below.

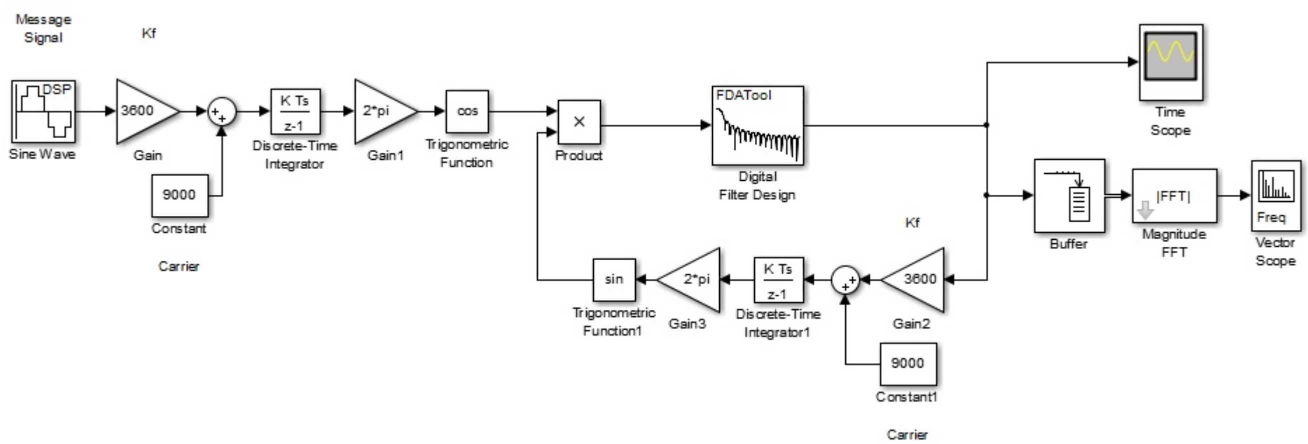

Figure 2. Suggested FM DEmodulator for Simulation

Make it work first, and show the T.A.. Make sure the sinusoid you see on the output of the demodulator has the same frequency as the one input to the modulator.

2.3 Running and Testing Your Modulator and Demodulator

Two working projects are given to you within `Code Composer Studio` under the names

- `ECE316_Exp03a_FM_MOD` and
- `ECE316_Exp03b_FM_DEMOD`.

2.3.1 FM Modulator

After opening your FM modulator project, compile, download and run it, and make sure it works. The input to your modulator will be a 100 Hz, $1V_{pp}$ sinusoid from the signal generator. Make sure you adjust your signal generator to use the `High Z Load` setting, and that the output button is on. One channel will display the input (or message) signal and the other the FM signal modulated with the input.

Just like the system you have simulated, your FM signal will vary 3600 Hertz per Volt of the input signal, having 12000Hz (carrier) as a centre frequency. Remember, FM changes the **instantaneous frequency** of the carrier, not its amplitude.

Put your modulator to run, and answer some questions in the answer sheet.

2.3.2 FM Demodulator

Now make the demodulator project your active project by clicking on it. Look at the code and see if you can understand what is taking place. As input to the demodulator, set *your signal generator* to generate FM, 4000Hz deviation, 12KHz carrier and 1KHz sinusoidal message signal. Please, check on the oscilloscope if your input is correct prior to calling a TA.

Compile, download and run the project. Move on to the answer sheet and answer some of the remaining questions.

3. Two Steps Further

You can go a little further and do the following two things, or one of them at least if you have the time.

First, if you are running a modulator, have a neighbouring group run the demodulator. Connect one board to the other using coaxial cables and test the whole system. Then you can use music as an input and listen to the output with a loudspeaker and see if this really works.

Then, if you are brave enough, try out viewing your favourite radio station on the Spectrum Analyzer. You will need to know the frequency of its carrier (in MHz) and a make-shift antenna. Set the spectrum analyzer to start at frequency 88.1MHz and end at 108MHz. By doing this you will be able to see all FM radio stations operating in Toronto. Choose one, and center the reading on the spectrum analyzer on it. Since by regulation every FM radio station has about 200MHz for its operation, you can change the span on the spectrum analyzer to be 200MHz. If you'd like to listen to what is being displayed on your spectrum analyzer, turn on an FM radio and listen to it.

4. Accomplishments

In this experiment, you were required to design and simulate an FM modulator and demodulator, and to implement these on a DSP platform using a given program. 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 as they were implemented. All of these concepts are widely used in the study of communication systems.

Acknowledgments

Thanks for all the students who have provided input on the previous versions of this experiment.

References

[1] S. Haykin and M. Moher. *Introduction to Analog and Digital Communications, 2nd. Ed.* Wiley, 2007.

[2] B.P. Lathi. *Modern Digital and Analog Communication Systems, 3rd Ed.* Oxford University Press, 1998.