Binary ASK Transmitter*

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	This module refers to LabVIEW, a software development environment that features a graphical programming language. Please see the LabVIEW QuickStart Guide[1] module for tutorials and documentation that will help you:
	• Apply LabVIEW to Audio Signal Processing
	• Get started with LabVIEW
	• Obtain a fully-functional evaluation edition of LabVIEW

Table 1

NOTE: Visit LabVIEW Setup[2] to learn how to adjust your own LabVIEW environment to match the settings used by the LabVIEW screencast video(s) in this module. Click the "Fullscreen" button at the lower right corner of the video player if the video does not fit properly within your browser window.

1 Summary

Three parameters specify a sinusoidal carrier wave: amplitude, frequency, and phase. An individual parameter or combination of parameters may be **modulated** by a message to communicate information. The most basic modulation schemes switch a single parameter between two values to signal a binary 0 or binary 1.

In this project, construct and study a transmitter that switches the carrier wave's amplitude between zero and a non-zero value. The term **switching** is also called **keying** (as in a telegraph key), and so the transmitter in this project can be said to use **binary amplitude shift keying** (**binary ASK**).

2 Objectives

1. Study the spectral characteristics of binary ASK signals using both rectangular and raised cosine pulse shapes
2. Translate the ASK transmitter block diagram into a LabVIEW block diagram
3. Develop an ASK transmitter for the speaker-air-microphone (SAM) channel

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3 Deliverables

1. Summary write-up of your results
2. Hardcopy of all LabVIEW code that you develop (block diagrams and front panels)
3. Any plots or diagrams requested

NOTE: You can easily export LabVIEW front-panel waveform plots directly to your report. Right-click on the waveform indicator and choose "Export Simplified Image."

4 Setup

1. LabVIEW 8.5 or later version
2. Computer soundcard
3. Speaker

5 Textbook Linkages

Refer to the following textbooks for additional background on the project activities of this module; see the "References" section below for publication details:

- Carlson, Crilly, and Rutledge – Ch 14
- Couch – Ch 5
- Haykin and Moher – Ch 7
- Lathi – Ch 13
- Proakis and Salehi (FCS) – Ch 10
- Stern and Mahmoud – Ch 5

6 Prerequisite Modules

Complete the lab project Speaker-Air-Microphone (SAM) Channel Characterization[3] before you begin this project.

If you are relatively new to LabVIEW, consider taking the course LabVIEW Techniques for Audio Signal Processing[4] which provides the foundation you need to complete this project activity, including: block diagram editing techniques, essential programming structures, subVIs, arrays, and audio.

7 Introduction

Bandpass channels possess a non-zero lower cutoff frequency, and therefore cannot transmit a **baseband** signal. For example, the channel established between two voice-grade telephones begins at 300 Hz and ends at 3,000 Hz. A digital signal (baseband type) must be shifted in frequency so that its significant frequency components all exist within the 300 to 3,000 Hz range. Frequency shifting may be accomplished by impressing the baseband signal onto a sinusoidal **carrier wave**.

A sinusoidal carrier wave $c(t) = A_c \cos(2\pi f_c t + \varphi_c)$ possesses three parameters that can be switched (or keyed) by a binary message signal: **amplitude**, **frequency**, and **phase**; the resulting **digital continuous wave modulation** schemes are called ASK (amplitude shift keying), FSK (frequency shift keying), and PSK (phase shift keying), respectively.

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[3]"Speaker-Air-Microphone (SAM) Channel Characterization" <http://cnx.org/content/m18666/latest/>
[4]*Musical Signal Processing with LabVIEW – Programming Techniques for Audio Signal Processing* <http://cnx.org/content/col10440/latest/>

The Figure 1 screencast video introduces the mathematical notation used in this module to discuss ASK modulation, and includes a visualization of the ASK waveform.

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Figure 1: [video] Mathematical notation for ASK modulation and visualization of the ASK waveform

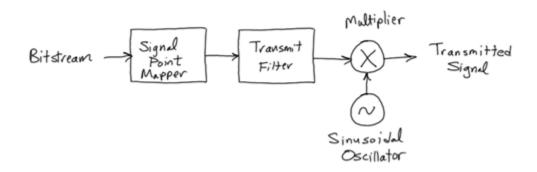Figure 2 illustrates the block diagram of a binary ASK transmitter.

Figure 2: ASK transmitter block diagram

The transmitter's **signal point mapper** selects a value for each bit of the binary message (bitstream), and the **transmit filter** generates an analog signal waveform to be transmitted through the channel. The transmit filter is also known as the **pulse shaping filter**. Binary ASK maps a binary 1 to $\sqrt{E_b}$ and a binary 0 to zero; E_b denotes the energy per bit. The transmit filter scales a standard pulse shape by these values to produce the baseband signal, which in turn is shifted in frequency to match the channel's center frequency by multiplying by a sinusoidal carrier waveform to produce the transmitted signal. The Figure 3 screencast video discusses the spectrum of the transmitted signal, especially the impact of a rectangular pulse shape on the required bandwidth of the ASK signal.

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Figure 3: [video] ASK spectrum with rectangular pulses

As discussed in the previous video, the ASK signal created with rectangular pulses is spectrally inefficient. From an intuitive point of view, signals with sharp corners always possess a wideband spectrum. Rounding

the corners should therefore produce a transmitted signal that does not require as much bandwidth.

The **raised cosine pulse** is a standard pulse shape widely used in communication systems that offers much better spectral efficiency; see the video in pam_RaisedCosinePulse.vi[5] for more background on this important pulse shape, including an explanation of its **excess bandwidth** pulse shape parameter. The Figure 4 screencast video discusses the spectrum of the transmitted ASK signal with raised cosine pulse shaping.

Figure 4: [video] ASK spectrum with raised cosine pulse shaping

Consider once again the transmitter block diagram of Figure 2. In a fully digital implementation, the pulse shaping filter output must be a sampled-value waveform. Rectangular pulse shapes are easy to implement: a given binary symbol simply maps to an array of constant values. Nonrectangular pulses take a bit more effort, however, especially when the pulse shape must extend over more than one bit interval.

The Figure 5 screencast video describes a pulse shaping filter implementation that can be used with any pulse shape. The basic idea involves driving an FIR filter with an impulse train.

Figure 5: [video] Signal point mapper and pulse shaping filter implementation using an FIR filter driven by an impulse train

8 Procedure

8.1 SubVI construction

Build the subVIs listed below. You may already have some of these available from previous projects.

Demonstrate that each of these subVIs works properly before continuing to the next part.

1. util_BitstreamFromRandom.vi[6]
2. pam_SignalPointMapper.vi[7]
3. pam_TransmitFilter.vi[8]
4. pam_RectanglePulse.vi[9]
5. pam_RaisedCosinePulse.vi[10]
6. bpm_ProductModulator.vi[11]

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[5] "pam_RaisedCosinePulse.vi" <http://cnx.org/content/m18566/latest/>
[6] "util_BitstreamFromRandom.vi" <http://cnx.org/content/m18528/latest/>
[7] "pam_SignalPointMapper.vi" <http://cnx.org/content/m18570/latest/>
[8] "pam_TransmitFilter.vi" <http://cnx.org/content/m18472/latest/>
[9] "pam_RectanglePulse.vi" <http://cnx.org/content/m18454/latest/>
[10] "pam_RaisedCosinePulse.vi" <http://cnx.org/content/m18566/latest/>
[11] "bpm_ProductModulator.vi" <http://cnx.org/content/m18556/latest/>

8.2 ASK transmitter

Assemble an ASK transmitter using the subVIs you created in the previous step; refer to the ASK transmitter diagram of Figure 2. Drive the transmitter with a random bitstream containing equiprobable binary values. Plot the power spectrum of the ASK signal using the "Express | Signal Analysis | Spectral Measurements" Express subVI. Connect the transmitter output to the speaker using the technique you learned in Speaker-Air-Microphone Channel Characterization[12].

Include the following controls on the front panel:

- `fc, carrier frequency [Hz]`
- `fs, sampling frequency [Hz]`
- `Eb, energy per bit`
- `Tb, bit interval [s]`
- `bitstream length`
- `seed`

Include the following indicators on the front panel:

- `ASK power spectrum` – waveform graph
- `time domain` – transmit filter and product modulator signals overlaid on the same waveform graph
- `Rb, bit rate [Hz]`
- `samples per bit interval`
- `total signal duration [s]`

Figure 6 illustrates a suggested layout for the VI front panel and shows the expected results of the initial parameter choices for the next section.

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[12]"Speaker-Air-Microphone (SAM) Channel Characterization" <http://cnx.org/content/m18666/latest/>
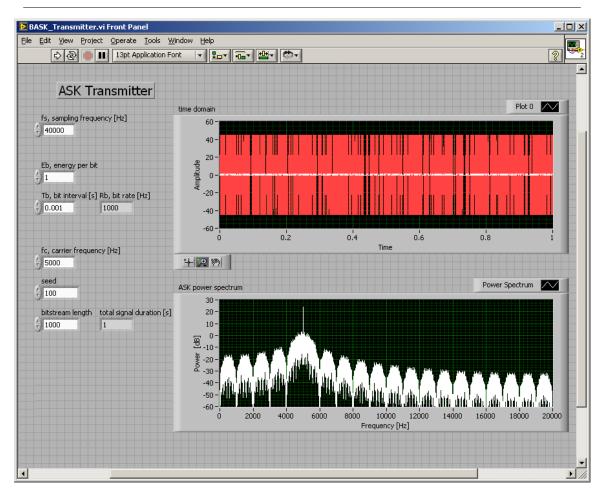
Figure 6: ASK transmitter VI front panel (click image to see fullsize version)

8.3 ASK transmitter parameter experiments

Begin with the following front panel control values:

- `fc, carrier frequency [Hz]` = 5,000 Hz
- `fs, sampling frequency [Hz]` = 40,000 Hz
- `Eb, energy per bit` = 1
- `Tb, bit interval [s]` = 0.001 s
- `bitstream length` = 1000
- `seed` = -1

These values should produce a bit rate of 1,000 Hz and total signal duration of 1 second.

1. Run the VI several times. You should observe a different sequence for the bitstream for each run. Next, change the `seed` to an integer larger than -1 and run the VI several times again. You should

now observe the bitstream sequence to be the same for each run. Use a seed value other that -1 to generate a constant bitstream sequence, when needed.

2. Vary the bit energy E_b and study the time-domain signals and power spectrum. Summarize the behavior of the signals as a function of E_b.

3. Vary the bit interval T_b and study the time-domain signals and power spectrum. Summarize the behavior of the signals as a function of T_b. Be sure to comment on the following points: (a) What does ASK sound like for a long bit interval such as 0.01 seconds compared to a short bit interval such as 0.0005 seconds? (b) How does the bit rate value manifest itself in the power spectrum display? Hint: Recall what you know about the first-null bandwidth of a sinc function. (c) How does the choice of bit interval affect the total time to transmit the message?

4. Vary the carrier frequency f_c and study the time-domain signals and power spectrum. Summarize the behavior of the signals as a function of f_c.

5. Reset the front panel controls to the initial value listed at the beginning of this section. Change the carrier frequency to 5,001 Hz, then to 5,002 Hz, and so on in small steps. What change do you observe in the sound of the ASK signal and the time-domain plot? Hint: zoom in on the ASK signal waveform so that you can see the signal between bit transition. Draw a conclusion: what relationship must exist between the carrier frequency f_c and the bit interval T_b to ensure that chopped edges do not occur?

Plot time-domain waveforms and power spectra for several representative choices of parameter values.

8.4 ASK transmitter parameter experiments: raised cosine pulse shaping

1. Modify the VI front panel to include a Boolean control to conveniently switch between rectangular and raised cosine pulse shapes. Use a case structure on the block diagram to generate the two types of pulse shapes. Include front panel controls for the `alpha` (excess bandwidth) parameter and `bit intervals for support` controls of the pam_RaisedCosinePulse.vi[13] subVI.

2. Adjust the front panel control values to match those specified at the beginning of the previous section.

3. Select a rectangular pulse shape, and run the VI one time with autoscaling enabled on the power spectrum display. Right-click on the Y-axis of the power spectrum display and uncheck the "AutoScale Y" option. Next, select the raised cosine pulse shape and run the VI again. Zoom in on the time-domain signal plot, and disable autoscaling on the X-axis to ensure that the zoom level is retained from one run of the VI to the next.

4. Experiment with different values of the raised cosine pulse controls, then compare your results to those of the rectangular pulse shape. Be sure to comment on the following points: (a) signal shape in the time domain, (b) signal shape in the frequency domain (power spectrum), and (c) sound of the transmitted signal – try a larger bit interval (and short bitstream length) so that you can clearly hear the difference between rectangular and raised cosine pulse shaping).

5. Recall the work that you did to characterize the SAM channel in Speaker-Air-Microphone (SAM) Channel Characterization[14], especially the lower and upper passband limits. Select raised cosine pulse shaping, and then choose values for carrier frequency and bit interval to make the transmitted signal fully occupy the channel passband region. State your two values. Listen to this signal for a bit – what does a "fully utilized channel" sound like? Can you perhaps now explain some parts of a typical telephone dial-up modem initiation sequence[15] ? (Click link to listen).

9 References

1. Carlson, A. Bruce, Paul B. Crilly, and Janet C. Rutledge, "Communication Systems," 4th ed., McGraw-Hill, 2002. ISBN-13: 978-0-07-011127-1

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[13]"pam_RaisedCosinePulse.vi" <http://cnx.org/content/m18566/latest/>

[14]"Speaker-Air-Microphone (SAM) Channel Characterization" <http://cnx.org/content/m18666/latest/>

[15]http://cnx.org/content/m18668/latest/dialup-modem.mp3

2. Couch, Leon W. II, "Digital and Analog Communication Systems," 7th ed., Pearson Prentice Hall, 2007. ISBN-10: 0-13-142492-0

3. Haykin, Simon, and Michael Moher, "Introduction to Analog and Digital Communication Systems," 2nd ed., Wiley, 2007. ISBN-13: 978-0-471-43222-7

4. Lathi, Bhagwandas P., "Modern Digital and Analog Communication Systems," 3rd ed., Oxford University Press, 1998. ISBN-10: 0-19-511009-9

5. Proakis, John G., and Masoud Salehi, "Fundamentals of Communication Systems," Pearson Prentice Hall, 2005. ISBN-10: 0-13-147135-X

6. Stern, Harold P.E., and Samy A. Mahmoud, "Communication Systems," Pearson Prentice Hall, 2004. ISBN-10: 0-13-040268-0