Telecommunications
Communications Technologies

Pulse Modulation and Sampling (PAM / PWM / PPM)

Courseware Sample

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Safety and Common Symbols

The following safety and common symbols may be used in this manual and on the equipment:

Symbol	Description
DANGER	**DANGER** indicates a hazard with a high level of risk which, if not avoided, will result in death or serious injury.
WARNING	**WARNING** indicates a hazard with a medium level of risk which, if not avoided, could result in death or serious injury.
CAUTION	**CAUTION** indicates a hazard with a low level of risk which, if not avoided, could result in minor or moderate injury.
CAUTION	**CAUTION** used without the *Caution, risk of danger* sign ⚠, indicates a hazard with a potentially hazardous situation which, if not avoided, may result in property damage.
	Caution, risk of electric shock
	Caution, hot surface
	Caution, risk of danger
	Caution, lifting hazard
	Caution, hand entanglement hazard
	Notice, non-ionizing radiation
	Direct current
	Alternating current
	Both direct and alternating current
	Three-phase alternating current
	Earth (ground) terminal

Safety and Common Symbols

Symbol	Description
	Protective conductor terminal
	Frame or chassis terminal
	Equipotentiality
	On (supply)
	Off (supply)
	Equipment protected throughout by double insulation or reinforced insulation
	In position of a bi-stable push control
	Out position of a bi-stable push control

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Preface

Digital communication offers so many advantages over analog communication that the majority of today's communications systems are digital.

Unlike analog communication systems, digital systems do not require accurate recovery of the transmitted waveform at the receiver end. Instead, the receiver periodically detects which waveform is being transmitted, among a limited number of possible waveforms, and maps the detected waveform back to the data it represents. This allows extremely low error rates, even when the signal has been corrupted by noise.

The digital circuits are often implemented using application specific integrated circuits (ASIC) and field-programmable gate arrays (FPGA). Although this "system-on-a-chip" approach is very effective for commercial and military applications, the resulting systems do not allow access to internal signals and data and are therefore poorly suited for educational use. It is for this reason that we designed the Communications Technologies Training System.

The Communications Technologies Training System, Model 8087, is a state-of-the-art communications training system. Specially designed for hands-on training, it facilitates the study of many different types of digital modulation/demodulation technologies such as PAM, PWM, PPM, PCM, Delta Modulation, ASK, FSK, and BPSK as well as spectrally efficient technologies such as QPSK, QAM, and ADSL. The system also enables the study of direct-sequence and frequency-hopping spread spectrum (DSSS and FHSS), two key technologies used in modern wireless communication systems (CDMA cellular-telephony networks, Global Positioning System, Bluetooth interface for wireless connectivity, etc.) to implement code-division multiple access (CDMA), improve interference rejection, minimize interference with other systems, etc. The system is designed to reflect the standards commonly used in modern communications systems.

Unlike conventional, hardware-based training systems that use a variety of physical modules to implement different technologies and instruments, the Communications Technologies Training System is based on a Reconfigurable Training Module (RTM) and the Communications Technologies (LVCT) software, providing tremendous flexibility at a reduced cost.

Each of the communications technologies to be studied is provided as an application that can be selected from a menu. Once loaded into the LVCT software, the selected application configures the RTM to implement the communications technology, and provides a specially designed user interface for the student.

The LVCT software provides settings for full user control over the operating parameters of each communications technology application. Functional block diagrams for the circuits involved are shown on screen. The digital or analog signals at various points in the circuits can be viewed and analyzed using the virtual instruments included in the software. In addition, some of these signals are made available at physical connectors on the RTM and can be displayed and measured using conventional instruments.

The courseware for the Communications Technologies Training System consists of a series of student manuals covering the different technologies as well as instructor guides that provide the answers to procedure step questions and to

review questions. The Communications Technologies Training System and the accompanying courseware provide a complete study program for these key information-age technologies.

We invite readers of this manual to send us their tips, feedback, and suggestions for improving the book.

Please send these to did@de.festo.com.

The authors and Festo Didactic look forward to your comments.

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About This Manual

Manual Objective

When you have completed this manual, you will be familiar with the principles of pulse modulation and sampling. You will be familiar with the time and frequency domain characteristics of pulses and with the three basic types of pulse modulation: PAM, PWM, and PPM.

Description

This Student Manual is divided into several units each of which covers one topic. Each unit begins with an Introduction presenting important background information. Following this are a number of exercises designed to present the subject matter in convenient instructional segments. In each exercise, principles and concepts are presented first followed by a step-by-step, hands-on procedure to complete the learning process.

Each exercise contains:

- A clearly defined Exercise Objective
- A Discussion Outline listing the main points presented in the Discussion
- A Discussion of the theory involved
- A Procedure Outline listing the main sections in the Procedure
- A step-by-step Procedure in which the student observes and measures the important phenomena, including questions to help in understanding the important principles.
- A Conclusion
- Review Questions

In this manual, all New Terms are defined in the Glossary of New Terms. In addition, an index of New Terms is provided at the end of this manual.

Safety considerations

Safety symbols that may be used in this manual and on the equipment are listed in the Safety Symbols table at the beginning of the manual.

Safety procedures related to the tasks that you will be asked to perform are indicated in each exercise.

Make sure that you are wearing appropriate protective equipment when performing the tasks. You should never perform a task if you have any reason to think that a manipulation could be dangerous for you or your teammates.

Systems of units

Units are expressed using the International System of Units (SI) followed by units expressed in the U.S. customary system of units (between parentheses).

Conventions Used in This Manual

Colored sidebars contain complementary information that will be of interest to the reader.

Special character formats

New terms are shown in **bold colored characters** the first time they appear.

Important terms are shown in **bold colored characters** the first time they appear.

Notes provide details that should be noted by the reader.

Tips provide information on effectively using the system. These are particularly helpful for inexperienced users.

This symbol refers you to another manual or document.

Software commands and dialog box names are shown in color. "Choose *File* ▶ *Print*" means choose the *Print* command in the *File* menu.

Probe connections

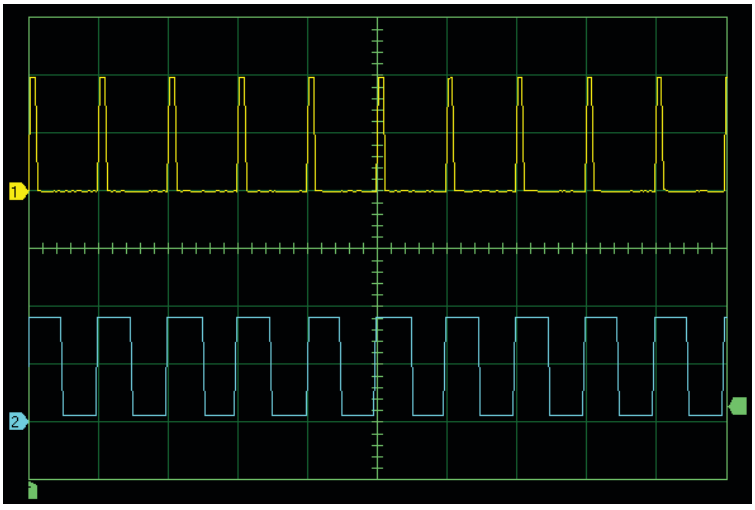
Instrument probe connections to test points are usually presented in tables showing the type of probe to use, the test point (TP) to connect it to, and the signal present at that test point:

Probe	Connect to	Signal
Oscilloscope 1	TP1	AUDIO INPUT
Oscilloscope 2	TP2	Low-pass Filter output
Spectrum Analyzer	TP2	Low-pass Filter output

System and instrument settings

Unless you are instructed to make specific settings, you can use any system and instrument settings that will allow you to observe the phenomena of interest. As a guide, important settings that were used to produce a figure may be shown beside the figure.

Oscilloscope Settings:
Channel 1 .....500 mV/div
Channel 2 .....2 V/div
Time Base..... 0.1 ms/div
Slope.....Rising
Trigger Level..... 0.5 V
Trigger Source..... Ch 2



List of Equipment Required

The following equipment is required to perform the procedures in this manual:

QTY	DESCRIPTION	MODEL
1	Power Supply	9408
1	Reconfigurable Training Module	9431
1	Data Acquisition Interface	9466
1	Analog/Digital Output Interface	9467
1	LVCT Software	9432-0
1	PAM / PWM / PPM Applications	9432-1
1	Cables and Accessories	9483

Additional Equipment

The LVCT software requires a current model computer running Windows® operating system. An Ethernet (100 Mb/s or better) network interface adapter is also required. A dual-output video adapter and two monitors are recommended to allow viewing the diagrams and the virtual instruments simultaneously.

The Communications Technologies Host Computer, Model 9695-A0, meets or exceeds these requirements.

Optional Equipment

You may wish to use a conventional oscilloscope (Model 797-20 or equivalent) and/or spectrum analyzer to observe the signals available at the BNC connectors and test points on the RTM (refer to the RTM Connections tab of the software to identify these outputs).

To the Instructor

You will find in this Instructor Guide all the elements included in the Student Manual together with the answers to all questions, results of measurements, graphs, explanations, suggestions, and, in some cases, instructions to help you guide the students through their learning process. All the information that applies to you is placed between markers and appears in red.

Accuracy of measurements

The numerical results of the hands-on exercises may differ from one student to another. For this reason, the results and answers given in this manual should be considered as a guide. Students who correctly performed the exercises should expect to demonstrate the principles involved and make observations and measurements similar to those given as answers.

Samples Exercises
Extracted from
the Student Manual
and the Instructor Guide

PAM Signals

EXERCISE OBJECTIVE

When you have completed this exercise, you will be familiar with the generation of both natural and flat-top sampled PAM signals. You will verify how the frequency and duty cycle of the sampling signal affect PAM signals as seen in the time domain.

DISCUSSION OUTLINE

The Discussion of this exercise covers the following points:

- Signal sampling
- PAM signal generation
- Sampling rate

DISCUSSION

Signal sampling

In Pulse-Amplitude Modulation (PAM) a pulse signal is used to sample an analog signal. The result is a train of constant-width pulses. The amplitude of each pulse is proportional to the amplitude of the message signal at the time of sampling.

Figure 2-2 and Figure 2-3 show the time domain appearance of a PAM signal for a triangle wave message signal. In the figures you can see that the PAM signal is made up of small segments (samples) of the message signal. As shown in the figures, two types of sampling are possible. Figure 2-2 represents natural sampling while Figure 2-3 is the result obtained with flat-top sampling.

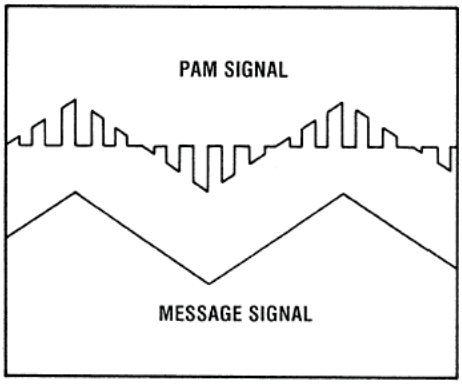


Figure 2-2. Natural sampling – time domain appearance of a PAM signal.

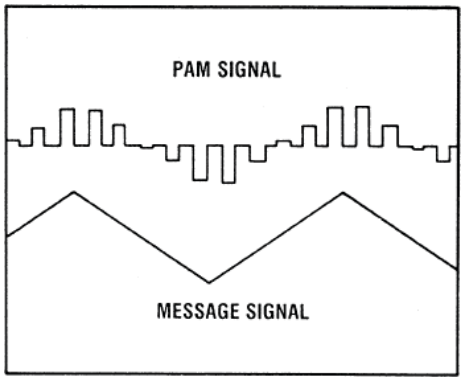


Figure 2-3. Flat-top sampling – time domain appearance of a PAM signal.

For a PAM signal produced with natural sampling, the sampled signal follows the waveform of the input signal during the time that each sample is taken. Flat-top sampling, however, produces pulses whose amplitude remains fixed during the sampling time. The amplitude value of the pulse depends on the amplitude of the input signal at the time of sampling.

PAM signal generation

A PAM signal is generated by using a pulse train, called the **sampling signal** (or clock signal) to operate an electronic switch or "chopper". This produces samples of the analog message signal, as shown in Figure 2-4.

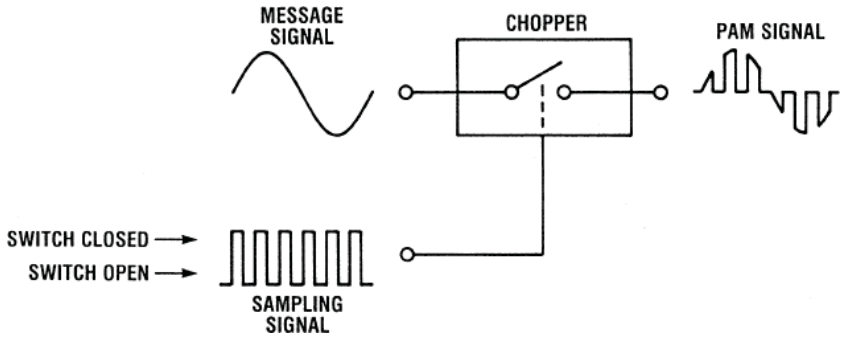


Figure 2-4. Natural sampling – generation of PAM signals.

The switch is closed for the duration of each pulse allowing the message signal at that sampling time to become part of the output. The switch is open for the remainder of each sampling period making the output zero. This type of sampling is called natural sampling.

For flat-top sampling, a sample-and-hold circuit is used in conjunction with the chopper to hold the amplitude of each pulse at a constant level during the sampling time, as shown in Figure 2-5.

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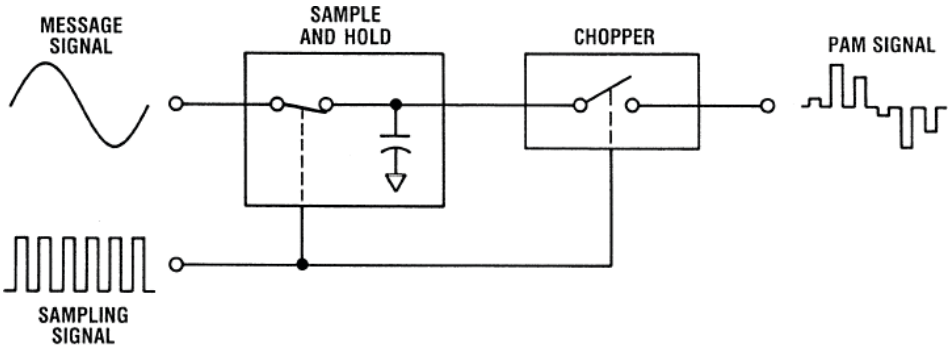

Figure 2-5. Flat-top sampling – generation of PAM signals.

Figure 2-6 shows the relationship between the message signal, the sampling signal, and the resulting PAM signal using natural sampling.

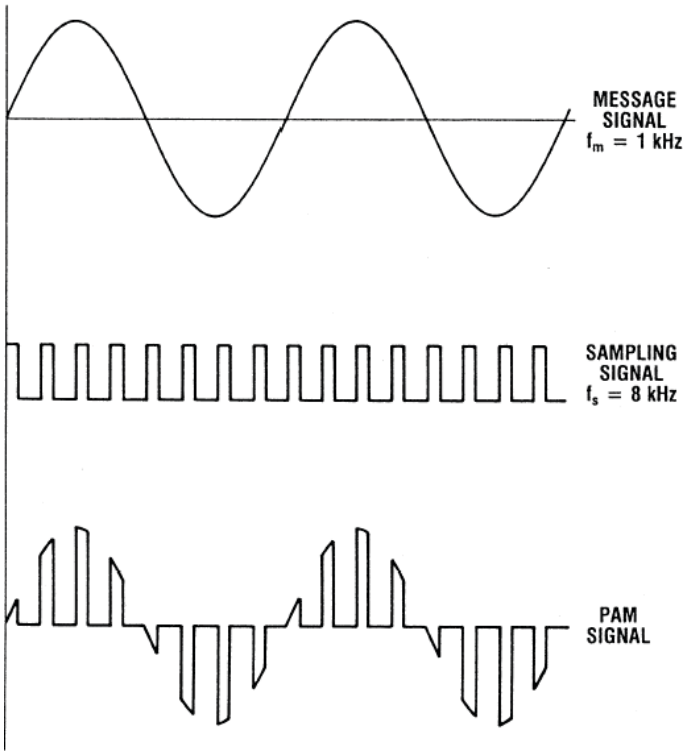

Figure 2-6. Natural sampling.

Sampling rate

The repetition rate of the sampling signal is called the sampling rate, or sampling frequency, and is abbreviated f_s. Observation in the time domain shows that, when the sampling rate f_s is much greater than the frequency of the message signal f_m, the PAM signal clearly resembles the message signal. If the sampling rate is reduced, or the message signal frequency is increased, the resemblance is less visible. It is neither f_s nor f_m alone that determines the degree of resemblance between the PAM and message signals, it is the ratio f_s/f_m. The lower this ratio, the less the resemblance.

If the pulses are narrow, PAM signals require little power for transmission and lend themselves easily to time-division multiplexing. Flat-topped pulses are easily regenerated by repeater stations and can be used for transmission over long distances. However, unlike other types of pulse modulation, PAM signals are affected by noise as much as analog signals are. Using PAM, therefore, offers little resistance or protection against noise in the transmission channel.

PROCEDURE OUTLINE

The Procedure is divided into the following sections:

- Set-up and connections
- Sampling rates
- Sampling modes and pulse width

PROCEDURE

Set-up and connections

1. Turn on the RTM Power Supply and the RTM and make sure the RTM power LED is lit.

File ▶ Restore Default Settings *returns all settings to their default values, but does not deactivate activated faults.*

2. Start the LVCT software. In the Application Selection box, choose *PAM* and click OK. This begins a new session with all settings set to their default values and with all faults deactivated.

   If the software is already running, choose *Exit* in the *File* menu and restart LVCT to begin a new session with all faults deactivated.

3. Make the Default external connections shown on the System Diagram tab of the software. For details of connections to the Reconfigurable Training Module, refer to the RTM Connections tab of the software.

   Click the Default button to show the required external connections.

4. As an option, connect a conventional oscilloscope to the PAM Generator OUTPUT using BNC T-connector.

   On-line help is accessible from the *Help* menu of the software and the *Help* menu of each instrument.

   You can print out the screen of any instrument by choosing *File* ▶ *Print* in that instrument.

Sampling rates

5. Make the following Generator Settings:

   Function Generator A:

   Function ..... Triangular
   Frequency (Hz) 1 000

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Function Generator B:

Function..... Pulse
Frequency (Hz)..... 10 000
Duty Cycle (%)..... 50
Apply Duty Cycle to Clock ..... On

6. Click the PAM Generator tab in order to display the PAM Generator diagram.

   On the PAM Generator, ensure that Nat. is selected for the Mode for natural sampling.

   Show the Probes bar (click in the toolbar or choose *View* ▶ *Probes Bar*). Connect the probes as follows:

Oscilloscope Probe	Connect to	Signal
1	TP1	AUDIO INPUT
2	TP8	OUTPUT
E	TP6	Buffered CLOCK INPUT

7. Show the Oscilloscope (click in the toolbar or choose *Instruments* ▶ *Oscilloscope*). Figure 2-7 shows an example of settings and what you should observe.

Oscilloscope Settings:
Channel 1..... 1 V/div
Channel 2..... 1 V/div
Channel E..... 2 V/div
Time Base..... 0.2 ms/div
Trigger Slope ..... Rising
Trigger Level..... 0.5 V
Trigger Source..... Ch 1

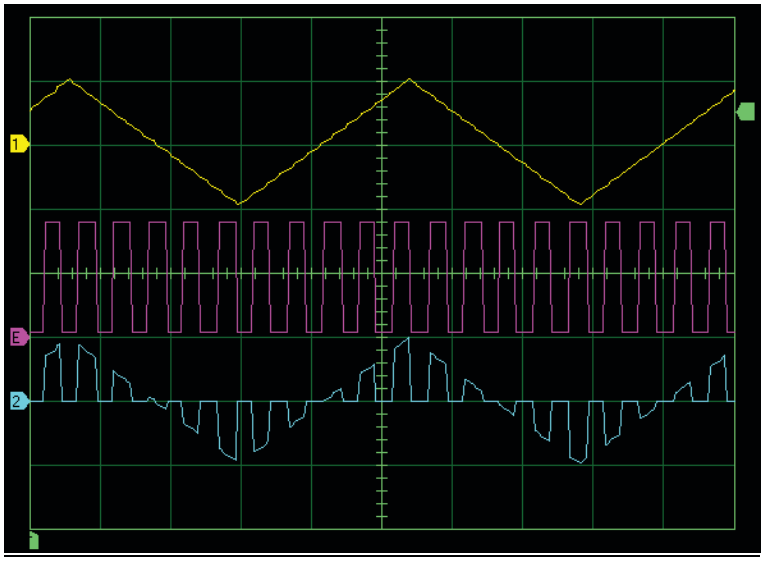

Figure 2-7. Message signal, 10 kHz sampling signal and PAM signal.

8. What does this display represent?

The time domain appearance of a PAM signal with natural sampling.

What is the ratio of the sampling frequency f_s to the message signal frequency f_m?

The ratio is f_s / f_m = 10 kHz / 1 kHz = 10

How many samples are taken of each cycle of the message signal?

10 samples

9. Decrease the sampling rate from 10 kHz to 5 kHz. Figure 2-8 shows an example of settings and what you should observe.

Oscilloscope Settings:
Channel 1.....1 V/div
Channel 2.....1 V/div
Channel E.....2 V/div
Time Base..... 0.2 ms/div
Trigger Slope .....Rising
Trigger Level..... 0.5 V
Trigger Source..... Ch 1

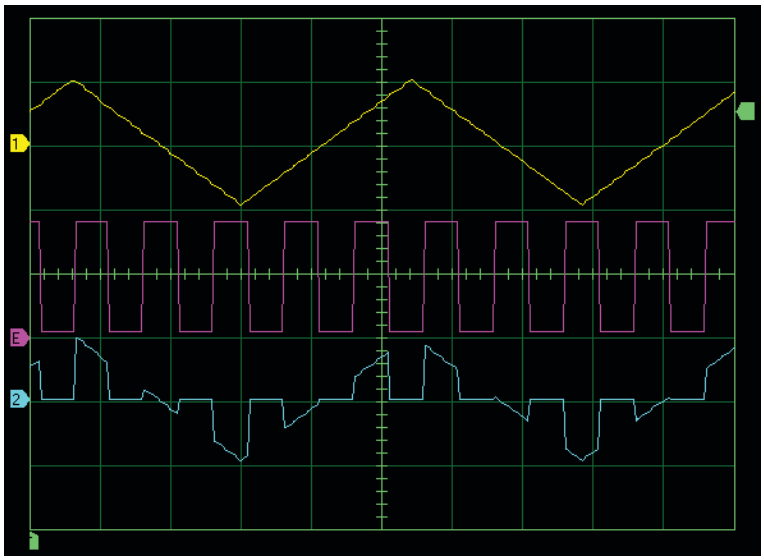

Figure 2-8. Message signal, 5 kHz sampling signal and PAM signal.

10. How does decreasing the frequency of the sampling signal by one half affect the PAM signal? Explain.

This reduces the number of samples taken per cycle of the message signal by one-half.

11. Decrease the frequency of the sampling signal to 3 kHz. Figure 2-9 shows an example of settings and what you should observe.

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Oscilloscope Settings:
Channel 1.....1 V/div
Channel 2.....1 V/div
Channel E.....2 V/div
Time Base..... 0.2 ms/div
Trigger Slope .....Rising
Trigger Level..... 0.5 V
Trigger Source..... Ch 1

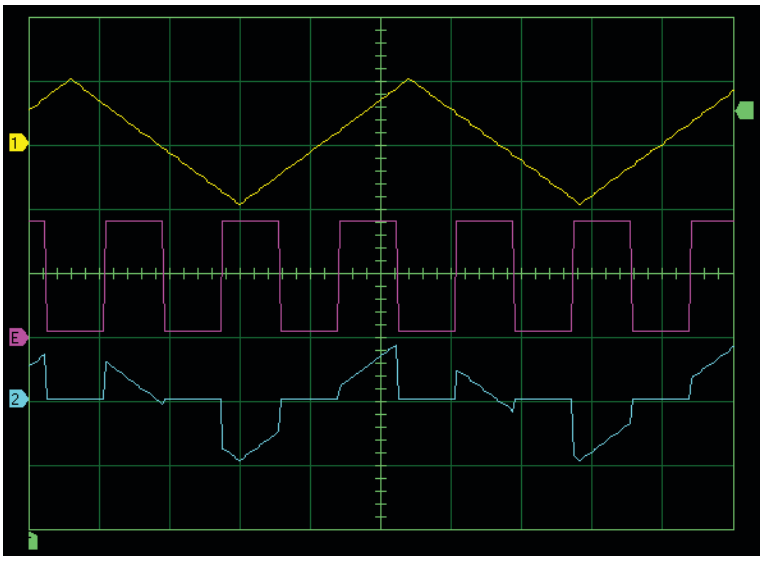

Figure 2-9. Message signal, 3 kHz sampling signal and PAM signal.

What is the ratio of the sampling frequency f_s to the message signal frequency f_m?

The ratio is f_s / f_m = 3 kHz / 1 kHz = 3

How many samples are taken of each cycle of the message signal?

3 samples

Is the message signal more or less recognizable in the PAM signal as the sampling frequency is decreased? Explain.

Less recognizable because there are fewer samples per cycle of the message signal.

12. On the PAM Generator, set the Mode *to* Flat to switch between natural and flat-top sampling. Describe the difference between the two types of signals.

With natural sampling the pulses follow the waveform of the message signal during the sampling time. With flat-top sampling, the amplitude is constant during the sampling time.

13. Vary the Duty Cycle (pulse width) of the sampling signal and observe the changes on the oscilloscope. Describe the effects on the PAM signal.

The width of the samples varies with the sampling signal pulse width.

Sampling modes and pulse width

14. Make the following Generator Settings:

Function Generator A:

Function	Sine
Frequency (Hz)	1 000

Function Generator B:

Function	Pulse
Frequency (Hz)	8 000
Duty Cycle (%)	50
Apply Duty Cycle to Clock	On

15. Observe the waveform of the PAM signal with natural sampling with narrow pulse (5% Duty Cycle) and with wide pulse (95% Duty Cycle). You can display both output signals on the oscilloscope simultaneously by using Memory location M1. The resulting output should resemble Figure 2-10

Click M1 or M2 in the instrument toolbar to store the current display in Memory 1 or Memory 2. Use the Memories setting to show the contents of Memory 1, Memory 2, or both.

Oscilloscope Settings:

Channel 2	1V/div
Time Base	0.2/div
Memory 1	On
Trigger Slope	Rising
Trigger Level	0.5
Trigger Source	Ch 2

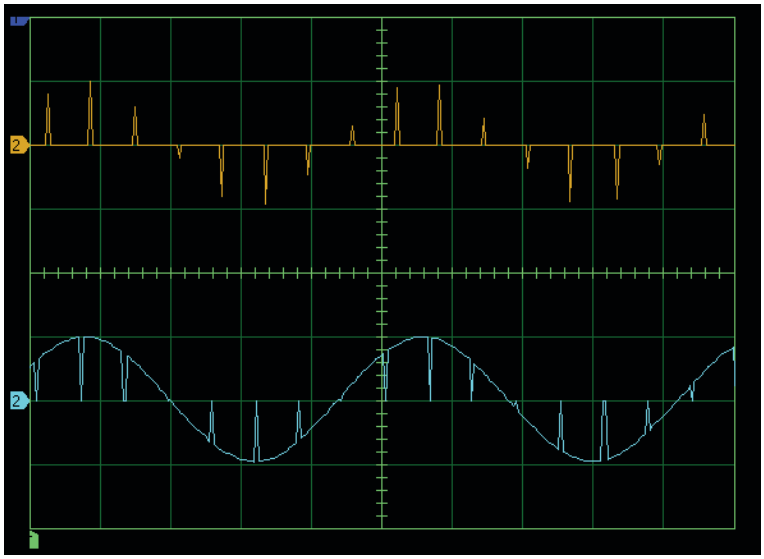

Figure 2-10. Natural sampling – narrow and wide sampling pulse.

Observe the waveform of the PAM signal with flat-top sampling with narrow pulse (5% Duty Cycle) and with wide pulse (95% Duty Cycle). You can display both output signals on the oscilloscope simultaneously by using Memory location M1. The resulting output should resemble Figure 2-11.

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Oscilloscope Settings:
Channel 2.....1V/div
Time Base.....0.2/div
Memory 1.....On
Trigger Slope .....Rising
Trigger Level.....0.5
Trigger Source.....Ch 2

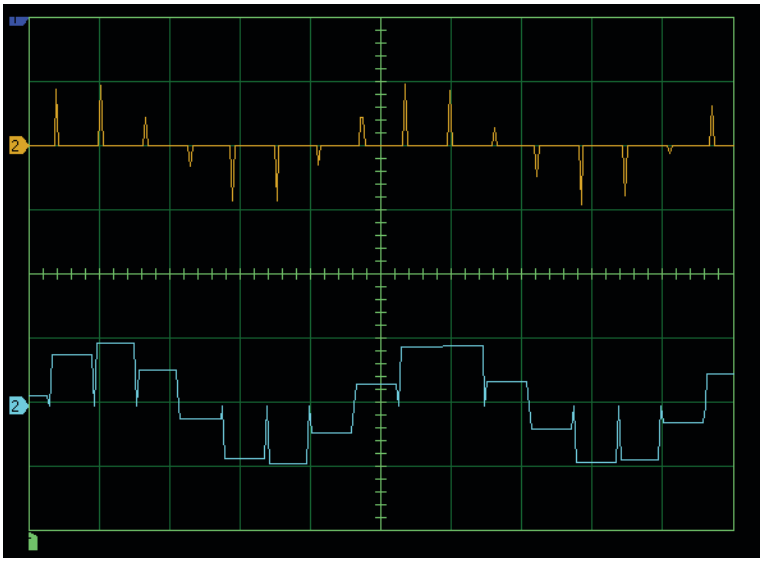

Figure 2-11. Flat-top sampling – narrow and wide sampling pulse.

Is there a great difference in appearance between natural and flat-top sampling

a) when the pulses are very narrow? Explain.

No because the pulses are very narrow, there is very little difference.

b) when the pulses are very wide? Explain.

Yes. When the pulses are wide, the naturally sampled signal resembles the message signal whereas the flat-top sampled signal does not.

16. Adjust the Gain on the PAM Generator from Min to Max. What effect does this have on the output?

The amplitude of the output increases and decreases with the Gain setting.

17. When you have finished using the system, exit the LVCT software and turn off the equipment.

CONCLUSION

In this exercise, you saw that PAM signals consist of samples of the message signal. You observed the differences between natural and flat-top sampling using different sampling rates and pulse-widths.

Review Questions

1. Describe the difference between natural and flat-top sampling?.

With natural sampling the PAM signal follows the waveform of the input signal during the sampling time. Flat-top sampling produces pulses with fixed amplitude during the sampling time.

2. What determines the amplitude of the samples for flat-top sampling?.

The amplitude of the message signal at the time of sampling.

3. If a periodic message signal with a frequency f_m is sampled at a sampling rate f_s , how would you determine the number of samples taken of each cycle of the message signal?.

The number of samples per cycle is equal to f_s / f_m.

4. Does the original message signal become more or less recognizable in a PAM signal when the sampling rate is increased?

More recognizable.

5. When the sampling signal pulses are wide, which sampling mode produces a PAM signal that closely resembles the message signal?

Natural sampling.

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