T-1 Time Division Multiplexing Lab

Introduction:

The goal of this lab is to introduce students to a number of fundamental concepts which have played and continue to play a crucial role in telecommunications technology. We hope that students will be able to gain a firm understanding of the following concepts: Time Division Multiplexing (TDM) as it applies to the structural and operational aspects of T-1; Pulse Code Modulation (PCM); Nyquist Sampling Theorem; Pulse Amplitude Modulation (PAM); Quantization; Companding; and Framing.

The Telecommunications Laboratory is equipped with two Vicom T-1 multiplexors and with test equipment that students should be familiar with from the Oscilloscopes Lab. In this lab you will use the function generator to input a simple sine wave of known frequency to a single channel of the transmitting side multiplexor. By probing the input and output of the appropriate channel interface modules and various test points on each multiplexor you will be able to observe and analyze the entire process of A-D and D-A conversion, TDM, and T-1 framing and transmission.

Each Vicom multiplexor is basically a channel bank. A channel bank is a device which takes 24 analog voice inputs, converts the analog voice into PCM, multiplexes all of the 64 kbps voice channels together and transmits the aggregate as a DS-1 signal (1.544 Mbps). On the input side, a channel bank receives a DS-1 signal, demultiplexes the 24 DS-0/PCM channels and converts each back into an analog voice signal. Each Vicom multiplexor has 24 6115-01 or 6120-01 module line cards. Each module interfaces to a single analog voice line. These are not interface modules which you can plug a normal telephone into. They require special signalling called E&M signalling which is provided by equipment such as a PBX.

Multiplexing equipment today is far more flexible and sophisticated than the channel banks used in this experiment; however, many of the basic concepts are still the same, and an understanding of these concepts paves the way toward understanding technologies such as packet switching and multiplexing, SONET and ATM.

Equipment and Setup:

There is only one T-1 multiplexor setup available in the Telecommunications Lab, **SLIS -835**. You **must sign-up** for time to use the equipment in the lab. While you may work in groups, we recommend that these groups **do not exceed 3 students** so that each member can profit from the experience.

Sign-up sheets will be posted on the bulletin board outside the lab. Groups may sign-up for more than one 1-hr slot if necessary; however please limit multiple sessions to different days. Please be prompt and be sure to show up during your selected time slot. Remember that this equipment must be shared among all students working on this lab.

- Estimated time: **1-2 hours**
- You are expected to be familiar with the purpose and operation of the test equipment used in this lab. Please refer to the **Oscilloscopes Lab** if you have questions or difficulty.
- You should prepare for this lab by reading the sections on digitization and multiplexing in the Halsall text. Those sections are found on pages 57 through 60.
- The following is a list of the equipment required for this lab. Consult with the on-duty GSA if you have any difficulty identifying correct equipment.

1	Leader LFG-1300S Function Generator .
1	BNC to 2 alligator clips cable for connecting function generator to line module inputs.
1	Tektronix 2225 Analog Oscilloscope.
2	Tektronix P6103 10x probes for analog oscilloscope channels.
1	Hewlett-Packard 54502A Digital Oscilloscope.
2	HP 10430A 10x probes for digital oscilloscope channels.
1	VICOM T-1 Mux rack - 2 Multiplexor/Channel Banks.
2	Push-Pin Connectors
2	1/4" Stereo Plugs

Table 1: Hardware required for T-1 lab.

Vicom Multiplexor and Test Equipment Setup:

Before beginning the lab, you must first set up the equipment. The function generator, the analog scope, the digital scope and the necessary probes should be in place next to the multiplexor setup. The rack houses the two T-1 multiplexors in a back-to-back configuration. We will use the multiplexor on the top as the transmitting side, and the multiplexor on the bottom as the receiving side.

During this lab you will use the function generator to input a sine wave onto one of the channels on the transmitting side multiplexer. Using the oscilloscopes you will be able to view the original analog signal, the received analog output signal and various points in between--including PAM wave representation of the signal, and the digital signal stream.

1. Setup the T-1 multiplexors (MUXs). Prepare the function generator, attach it to the transmit side of the MUX, and introduce a signal to the input of Channel 1:

- Check to see that the T-1's power strip is plugged in and turned on.
- Confirm that none of the leads are shorted (connected) together.
- Power on the function generator, and both oscilloscopes.
- Insert a 1/4" stereo plug into the XMT jack of Channel 1 (6115-1 module) on the upper (transmit) MUX.
- Insert another 1/4" stereo plug into the RCV jack of Channel 1 on the lower (receive) MUX
- Generate a small amplitude signal by **pressing in the 10dB** attenuation button on the function generator.
- Set the smallest amplitude possible with the 10dB attenuation by rotating the amplitude knob fully to the left.
- Select a **sine wave** with a frequency between 1kHz and 3kHz.
- Connect the function generator's red lead to the wire labeled 'tip' on the stereo plug in the XMT jack of the multiplexor.

2. Connect one channel of the analog scope to the transmit side of the MUX, and the other channel of the analog scope to the receive side of the MUX. In this configuration, you can simultaneously monitor both the signal input to the MUX and the signal output from the MUX.

- Connect Channel 1 of the analog scope to the wire labeled as the 'tip' of the stereo plug on the transmit multiplexor.
- Connect Channel 2 of the analog scope to the 'tip' wire of the stereo plug on the receive multiplexor
- **Note:** If the wires are not labeled on the stereo plug, please see the GSA. If the leads are not connected correctly you will not obtain a clear signal.

Lab Procedures

Part I - Analog Input and Output Signals

Input and Output:

1. When the equipment setup is complete, you can display the signal input to one channel of the T-1 Multiplexor and simultaneously display the signal output from that same channel on the receive side of the multiplexor by using the analog oscilloscope. You will then be asked to draw a graph of the signals that you observed:

- On the analog scope, select **CH1** on the channel selection switch (labeled: CH1/BOTH/CH2) to display the input signal to the transmit multiplexor.
- (1.1) Measure the peak-to-peak voltage ($\mathbf{V_{pp}}$) of the **input signal** (CH1 on scope): _____ Volts

  NOTE: the signal will probably be 'fuzzy', so estimate by measuring the distance between the signal's positive and negative peaks.

- (1.2) Draw the input signal on graph 1; showing the appropriate scales. The graph section can be found at the end of this lab, and it contains blank scope grids for drawing oscilloscope traces.

- Select **CH2** on the channel selection switch (labeled: CH1/BOTH/CH2) to display the output signal from the receive multiplexor.
- (1.3) Measure $\mathbf{V_{pp}}$ of the **output signal** (CH2 on scope): _____ Volts
- (1.4) Draw the output signal on graph 2, found in the graph section at the end of the lab, showing the appropriate scales.

Attenuation:

2. Next, you will observe the effect of removing the 10dB of attenuation from the output signal of the function generator, which can also be called the input signal to the multiplexor. To do so, both channels must be displayed on the analog scope simultaneously.

- Select **'BOTH'** on CH1/BOTH/CH2.
- Turn off the 10dB attenuation button on the function generator by setting it to the **OUT position**.
- (2.1) Why does the receive multiplexor output signal become distorted?
- Reset the 10dB attenuation button to the **IN position**.

Bandwidth and Cutoff Frequency:

3. The input section of each T-1 channel has a low-pass filter. This filter limits the frequencies that a Channel is capable of handling. You will observe the behavior of the multiplexor when a signal with a frequency that exceeds the filter's cutoff frequency is input to one of the multiplexor's channels. Both channels should be displayed on the analog scope simultaneously during this observation.

- Set the Function Generator for a 2kHz sine wave. Use the 10k multiplier button and set the frequency control knob to 0.2.
- While observing the display on the analog scope, gradually increase the function generator's output signal by slowly turning the frequency wheel counterclockwise.
- (3.1) At approximately what frequency does the output signal 'break' (when does it begin to drop significantly)? _____ __hertz
- (3.2) Using what you know about Nyquist's Theorem, what changes in the shape of the signal would have occurred without the low-pass filter?
- Set the function generator back to 1 KHz. Use 10K multiplier and set the frequency to 0.1.

Part II - Pulse Amplitude Modulation

Overview:

The VICOM T-1 uses a two-stage approach to producing a digital multiplexed signal. In the first stage, the 24 analog input channels are sampled and multiplexed to produce a single analog PAM signal. The PAM wave includes one sample from each channel per sampling period. It is important to realize that this is still an analog signal. To achieve better resolution by reducing the noise introduced by quantization, this PAM signal is then companded by an analog circuit before going to the second stage.

The second stage quantizes the signal by encoding each PAM sample to a 8-bit digital segment. The result of this stage will be seen in a later section. At the receive multiplexor, the process is reversed: the digital signal is converted back to an analog companded PAM signal, which is then decompanded and demultiplexed into its 24 component channels.

This part of the lab will allow the student to look at the both the uncompanded and companded PAM signals on both the transmit and receive multiplexers by using the analog oscilloscope.

- For the following drawings, you should set the V/div and Sec/div settings so that at least one full cycle of the signal is shown, and the vertical size is as large as possible while still remaining wholly visible on the screen.
- You may have to adjust the triggering settings on the scope. Refer back to the Oscilloscopes Lab if you are unsure how to do this.

1. First, you will observe the input signal after it has been pulse-amplitude modulated, and you will draw a graph of those signals. Next, you will observe the pulse-amplitude modulated signal after it has been companded, and you will draw a graph of those signals.

- Connect **CH1** of the analog scope to the **PAM 1** test point on the **transmit MUX** using a push pin connector.
- (1.1) Noting the scale, draw the Pulse Amplitude Modulated signal on graph 3 , found in the graph section at the end of the lab.

- Connect **CH1** of the analog scope to the **PAM 2** test point on the **transmit MUX** using a push pin connector.
- (1.2) Noting the scale, draw the Companded-Pulse-Amplitude-Modulated signal, that was transmitted, on graph 4, found in the graph section at the end of the lab.

2. Switching to the receive multiplexor, you will observe the companded pulse-amplitude-modulated signal that has been received from the transmit multiplexor. You will be asked to draw a graph of the signal that you observed. Next, you will observe the pulse-amplitude-modulated signal after it has been decompanded. You will again be asked to draw a graph of the signal that you observed.

- Connect **CH1** of the analog scope to the **PAM 3** test point (6060-01 module lower multiplexor) on the **receive MUX** using a push-pin connector.
- (2.1) Noting the scale, draw the companded pulse-amplitude-modulated signal, that was received, on graph 5, found in the graph section at the end of the lab.
- Connect **CH1** of the analog scope to the **PAM 4** test point on the **receive MUX** using a push pin connector.
- (2.2) Noting the scale, draw the Decompanded-Pulse-Amplitude-Modulated signal, that was received, on graph 6, found in the graph section at the end of the lab,

3. Finally, turn off and disconnect the analog scope.

Part III - T-1 Data Rate Analysis:

Overview:

In the next few sections, the student will use the digital oscilloscope to measure the various bit rates associated with the T-1 multiplexer. First, the student will measure the data bit rate of the T-1 multiplexer, or the number of bits per second that are usable for data transmission.

Channel Data Rate

1. Internal to the multiplexor, each channel has a timing pulse which indicates when that channel is allowed to insert its PAM pulse into the multiplexed signal. Therefore, there is one pulse per channel per frame. The VICOM T-1 Multiplexer does not allow us to observe this signal for each channel; it does, however, let us look at the timing pulse for Channel 24. We will use this pulse to calculate the data bit rate of the multiplexor.

- Connect **CH1** of the digital scope to the test point labeled **CHAN 24** of the **transmit MUX** (6040-01 module) using a push pin connector. This is the timing pulse for Channel 24.
- On the digital scope, hit **AUTOSCALE**.

2. Next, configure the digital scope, so that you can observe the CHAN24 signal. You will use the display menu to connect the dots, and then use the time-base menu to properly view the signal. Finally, you will use the digital scope's Δt and Δv markers to measure the period of Channel 24's timing pulse; using those measurements, you will the framing and data rates of the multiplexor.

- Press the **DISPLAY** menu button.
- Set Display to **Norm**.
- Set **CONNECT DOTS** to **ON**.
- Press the **TIME BASE** menu button.
- Set **time base** to 50 **μs/div**.
- Set **reference** to **LEFT**.
- Set **delay** to **8 μs**.
- Depress Run-Stop button.
- Press the **Δt/Δv** menu button.
- (2.1) Use the Δt/Δv markers to measure the period of the Channel 24 timing pulse. Be sure to note the proper units: _____ __ s
- (2.2) There is one timing pulse per channel per frame. Thus, the frequency of this pulse will be equal to the frame rate of the multiplexor. What is the frame rate of the MUX? _____ frames per second.
- (2.3) Given that each channel uses 7 data bits + 1 signalling bit (for a total of 8 bits) per channel each frame, and that there are 24 channels per frame, use the answer to the previous question to calculate the data bit rate of the multiplexor: _____ __bps

  NOTE: this calculation does not include the framing bit.

Transmitted Bit Rate and Framing Bit Rate:

1. Next, you will measure the transmitted bit rate of the multiplexor. This is the total number of bits per second transmitted by the multiplexor. From this measurement, the student will be able to calculate the control bit rate of the multiplexor, or the number of bits per second the T-1 multiplexer uses to maintain synchronization. In this section, you will be using the digital scope to observe the PCM bit stream of the multiplexor.

- Connect **CH1** of the digital scope to the **PCM output** test point on the left side of the **transmit MUX** to display the Pulse Code Modulated bit stream.
- On the digital scope, hit **AUTOSCALE**.

2. Next, configure the digital scope, so that you can observe the Pulse Code Modulated bit stream. You will use the display menu to connect the dots, and then use the time-base menu to properly view the signal.

- Press the **DISPLAY** menu button.
- Set **CONNECT DOTS** to **ON**.
- Press the **TIME BASE** menu button.
- Set **time base** to 500 **ns/div**.
- Set **reference** to **LEFT**.
- Set **delay** to **8 μs**.

3. We wish to measure the transmitted bit rate of the multiplexor. To do so, we must be able to measure the time between two consecutive ‘1’ bits.

Note: In order to stop the display, hit the RUN/STOP button to toggle the signal display to ‘stopped’ mode. If there are at least two consecutive positive pulses (‘1’ bits) displayed, go on to the next step. If not, hit SINGLE repeatedly until you see two consecutive positive pulses. (SINGLE allows you to take one single screen sample of the input at a time.)

- Press the **Δt/Δv** menu button.
- (3.1) Use the Δt/Δv markers to directly measure the actual bit rate of the PCM bit stream (set the Δt markers to the rising edges of two consecutive ‘1’ bits with no '0' bits in between). **Note:** these bits will undergo Bipolar-RZ encoding before transmission. Measured bit rate: ____________ bps.
- (3.2) Given that there are 193 bits per frame, use the bit rate measured in step 3.1 to calculate the frame rate of the multiplexor: __________ frames/sec.
- (3.3) Using the results from step 3.2 above and step 2.3 in the previous section, how much of the bandwidth of a T1 line is used for framing information (show your calculation): _________bps.

- (3.4) What is the usable data rate of the T1 multiplexor: ____________bps.

Part IV - T-1 Framing Pattern:

Overview:

In this section, the student will use the digital scope to determine the framing bit pattern used by the VICOM T-1. Framing bits are used to maintain synchronization between two multiplexers. The student will look at the framing bit in two ways: first, the 'framing pulse' produced by the multiplexor will be viewed on channel 1 of the digital scope. Second, the 'framing bit' will be shown within the transmitted bit stream on channel 2 of the digital scope.

1. Display the framing pulse and the framing bit within the bit stream. Channel 1 of the digital scope will be connected to the SIG test point, and channel 2 of the digital scope will be connected to the PCM test point. Both of these jacks are on the transmit multiplexor.

- Connect **CH1** of the digital scope to the **SIG** test point on the **transmit MUX**.
- Connect **CH2** of the digital scope to the **PCM** test point on the **transmit MUX**.
- Press the **CHANNEL** menu button and set **CH1** to on.
- Set the **vertical scale** for **Channel 1** to **2 V/div**.
- Set the **offset** for **Channel 1** to **-5.0V**.
- Depress **TRIG**, set source to CH1.
- Set **CH2** to on. Adjust level control to -2.25V.
- Depress **Timebase**, set reference to Center
- Set the **vertical scale** for **Channel 2** to **2 V/div**.
- Set the **offset** for **Channel 2** to **0.0V**.
- Press the **TIMEBASE** menu button.
- Set **time base** for both channels to **500 ns/div**.
- Set **delay** to **0s**.
- Press the **DISPLAY** menu button and set **CONNECT DOTS** to **ON**.

2. You should now have the PCM bit stream signal at the bottom of the screen, and the framing pulse at the center of the screen. We will refer to the CH1 signal as the 'framing pulse'. The CH2 signal is the PCM signal, which contains the 'framing bit.' If you followed the directions above, you should have a '1' pulse displayed as the framing bit. You can see the framing bit in the PCM stream below the framing pulse and one bit to the right. You will note that this bit is always the same as the framing pulse.

- **Note:** There is a frame every 125μs, and there is a framing bit in every frame. This bit is not always a binary '1', though. A positive pulse is a 1, while no pulse represents a 0.
- (2.1) Using the DELAY setting in the TIMEBASE menu, determine the framing bit pattern:______________________
- **Hint:** Set the DELAY to 125us, 250us, 375us, 500us, etc., and note the value of the framing pulse at these positions. While you are doing this, notice the framing bit in the PCM stream.

Part V - Questions and Analysis:

1. What advantage is gained by using companding on the PAM signals instead of an uncompanded signal?

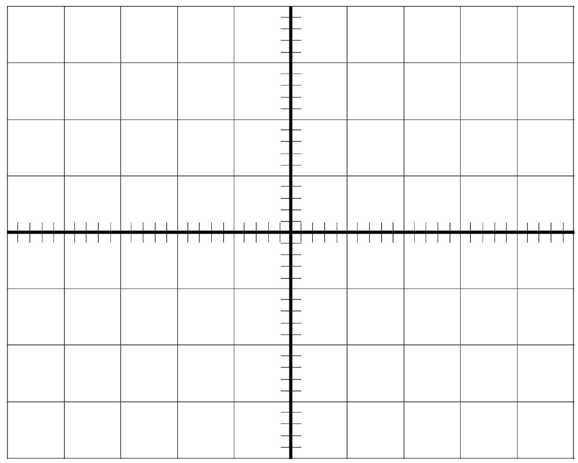
2. Give 3 reasons why a digital signal may be better than an analog signal for transmission over long distances.

3. Why is it necessary to utilize Bipolar RZ encoding on the PCM signal before transmitting it (i.e. why not just transmit the PCM signal)?

Part VI - Graph Section

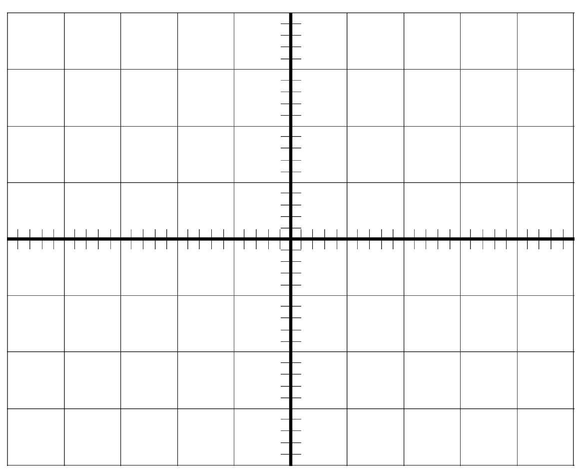
Below are the forms that you should use to complete the graphs in Part I and in Part II of this lab. Each graph is labeled by number and by the title of the graph.

Be neat, to scale, and concise.
Be sure to note the (scale) *V/div* and *Sec/div* settings.



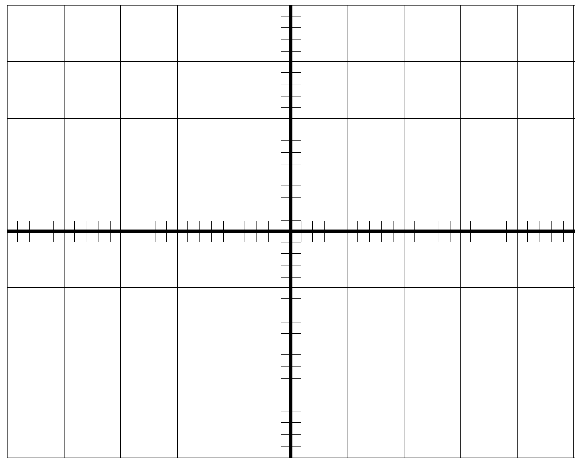
Graph 1: Analog Input Signal

Be neat, to scale, and concise.
Be sure to note the (scale) *V/div* and *Sec/div* settings.



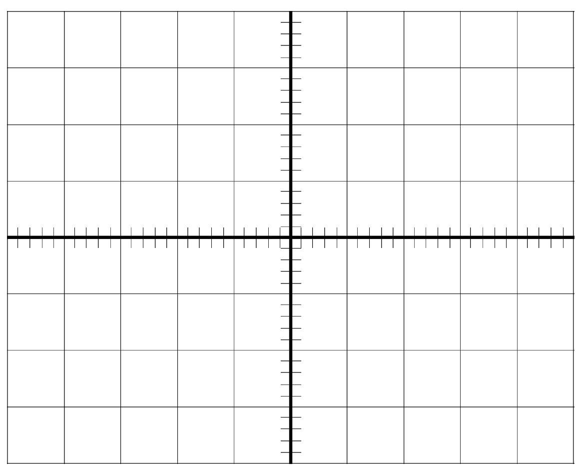
Graph 2: Analog Output Signal

Be neat, to scale, and concise.
Be sure to note the (scale) *V/div* and *Sec/div* settings.



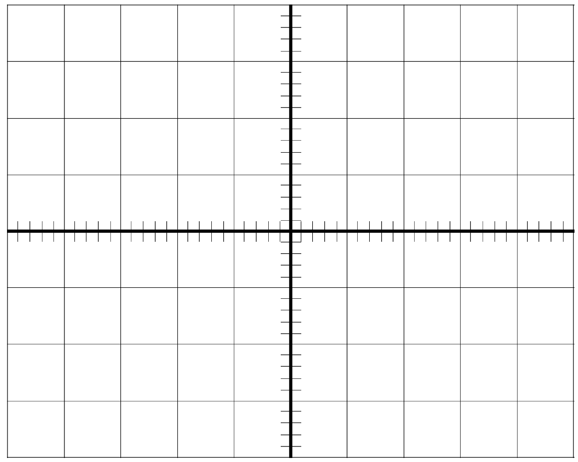
Graph 3: PAM-1

Be neat, to scale, and concise.
Be sure to note the (scale) *V/div* and *Sec/div* settings.



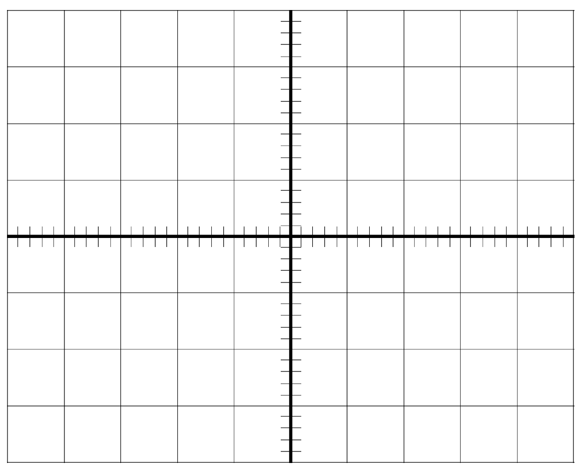
Graph 4: PAM 2

Be neat, to scale, and concise.
Be sure to note the (scale) *V/div* and *Sec/div* settings.



Graph 5: PAM-3

Be neat, to scale, and concise.
Be sure to note the (scale) *V/div* and *Sec/div* settings.



Graph 6: PAM-4