SCHOOL OF ELECTRICAL AND INFORMATION ENGINEERING

ELEC2302/9302 Signals and Systems — Lab 1

System characterisation

In this experiment you measure the impulse, step and frequency response of a real circuit: the baseband channel filters of the TIMS system.

Equipment

- Telecommunication Instructional Modelling System (TIMS) with the following modules:

Module	Qty	Type
Audio Oscillator	1	Movable module
Sequence Generator	1	Movable module
Baseband Channel Filters	1	Movable module
Frequency Counter	1	Fixed module
PC-based instrument inputs	1	Fixed module

- Banana-plug cables, for connections between TIMS modules.
- A PC with the Signals and Systems (S&S) software and PicoScope 6 or 7 installed.

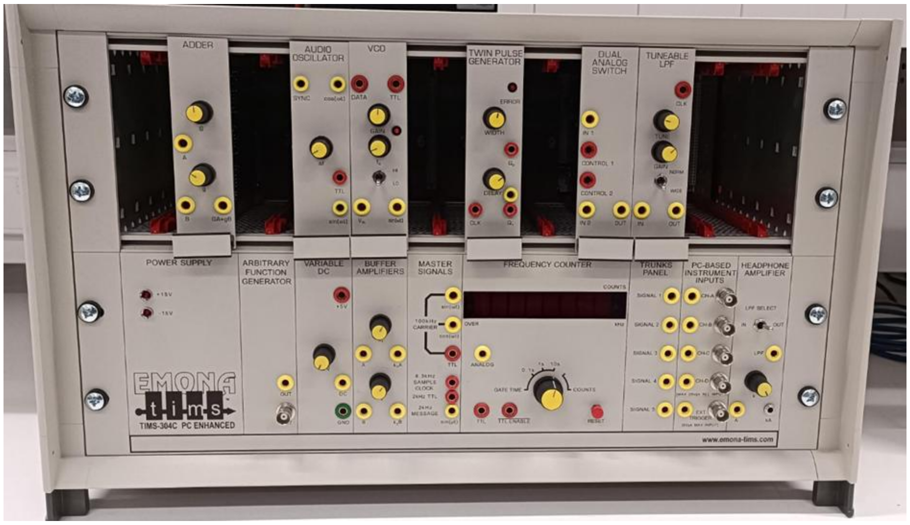

Figure 1: TIMS

Lab information

- Read this sheet before coming to the laboratory.
- Bring an exercise book: the observations you record in it are the record of the lab.
- There are three checkpoints in this sheet, each worth 1% of the unit mark. At each one, show your work to a tutor and answer the question they ask.

1 Linear time-invariant systems

Many physical systems are linear and time-invariant, or are modelled as LTI systems. A continuous-time LTI system is characterised completely by its impulse response $h(t)$: the output for *any* input is the convolution

$$y(t)=(h*u)(t)=\int_{-\infty}^{\infty} h(\sigma)u(t-\sigma)\mathrm{d}\sigma.$$

However, a true impulse $\delta(t)$ cannot be generated in the laboratory. So we probe the system with signals that can be generated. In this experiment, several filters are investigated through their responses to a step $H(t)$, to a narrow pulse $p_\tau(t)$, and to a sinusoid.

2 Introduction to TIMS

TIMS (Telecommunication Instructional Modelling System), shown in Figure 1, is a modular platform for building and testing signal processing and communication systems. Movable modules plug into any of the 12 upper slots and are interconnected with banana-plug cables. Fixed modules in the lower section provide common signals and measurement facilities.

The **PC-based instrument inputs** module connects TIMS to the PC. Signals from other TIMS modules can be connected directly to its banana-plug inputs and viewed in a program called PicoScope. Its BNC outputs provide the same signals to external instruments such as oscilloscopes. An external oscilloscope is optional for this experiment.

Rules for connecting modules

The following rules apply to every module in the TIMS system.

Socket	Meaning
Left-hand socket	Input
Right-hand socket	Output
Red socket	TTL levels (0 and 5 volts)
Yellow socket	Analog levels, nominally 4 V peak-to-peak, may be larger
Green socket	Common, ground or earth level

Do not connect yellow outputs to red inputs.

3 Starting up and using the PicoScope

Setting up the rack

Insert the movable modules listed in the equipment table into any of the 12 upper slots, then switch TIMS on. To view a TIMS signal in PicoScope, connect the module output to CH-A, CH-B or CH-C on **PC-based instrument inputs**. The signal then appears on the corresponding PicoScope channel. The BNC connectors provide the same signals to an external oscilloscope.

Connect the PicoScope to the PC via USB and to **PC-based instrument inputs** via BNC cables, unless these connections are already present. Then start PicoScope 6 or 7. The rest of the instructions here are based on PicoScope 6.

The PicoScope 6 window

The PicoScope 6 window is shown in Figure 2.

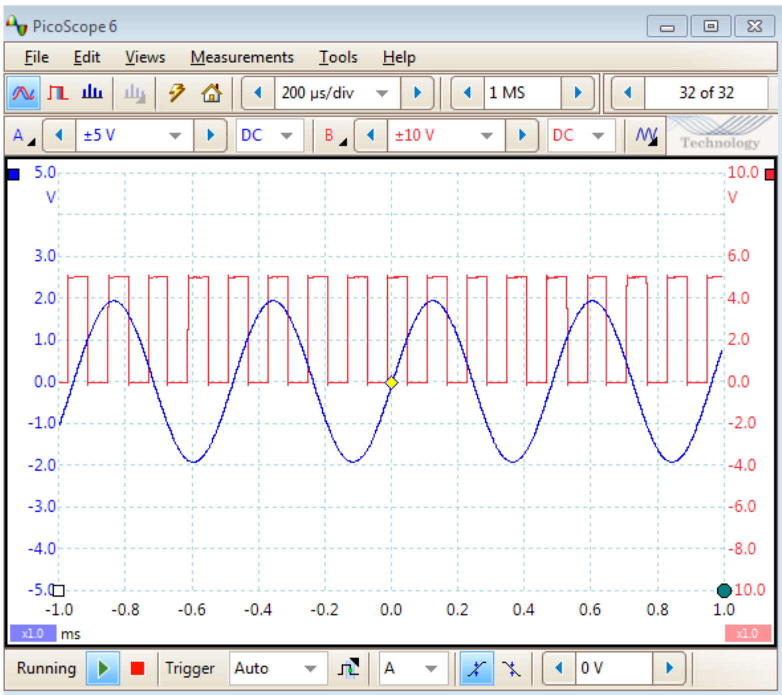

Figure 2: The PicoScope 6 window. The timebase and the per-channel vertical ranges are set from the toolbars at the top, and the trigger from the bar along the bottom

The main controls for what is displayed in PicoScope are:

- **Timebase**: horizontal scale (time/div)
- **Channels A–C**: vertical scale (volts/div) and AC/DC coupling
- **Resolution**: set each active channel to 12 bits (Figure 3)
- **Trigger**: use Auto; select the source channel and trigger level
- **Measurements**: use cursors or the Measurements menu

Recommended starting settings:

- Timebase: $500\mu s$/div
- CH-A: ±10V, DC
- CH-B: ±5V, DC

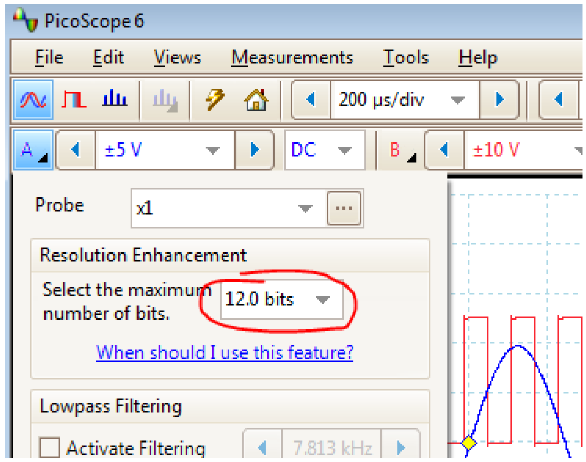

Figure 3: Setting the resolution of a channel to 12 bits

- Resolution: 12 bits
- Trigger: Auto

4 Experiments

4.1 Step response of a system

First we're going to look at the step response of the **Baseband Channel Filters**. The block diagram and the TIMS model of the setup are shown in Figure 4 and Figure 5. The IN of the **Baseband Channel Filters** is connected to the TTL output of the **Audio Oscillator**. The TTL output is a square wave, so each of its transitions is a step $H(t)$ (up to a scale factor and a time shift).

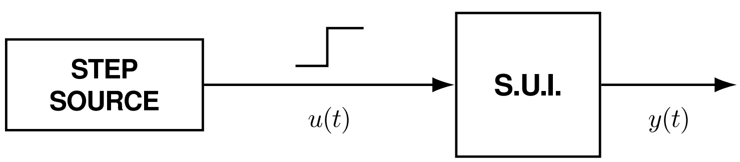

Figure 4: Block diagram of the step input. S.U.I. is the system under investigation

4.1.1 Procedure

1. Reduce the frequency to the minimum setting of the **Audio Oscillator**, around 0.25kHz, by turning the knob counter-clockwise
2. Connect the TTL of the **Audio Oscillator** to the TTL of the **Frequency Counter**
3. Check that the reading is around 0.25kHz and then disconnect the link
4. Connect the input $u(t)$ (TTL of the **Audio Oscillator**) to CH-A of the **PC-based instrument inputs** and the output $y(t)$ (OUT of the **Baseband Channel Filters**) to CH-B

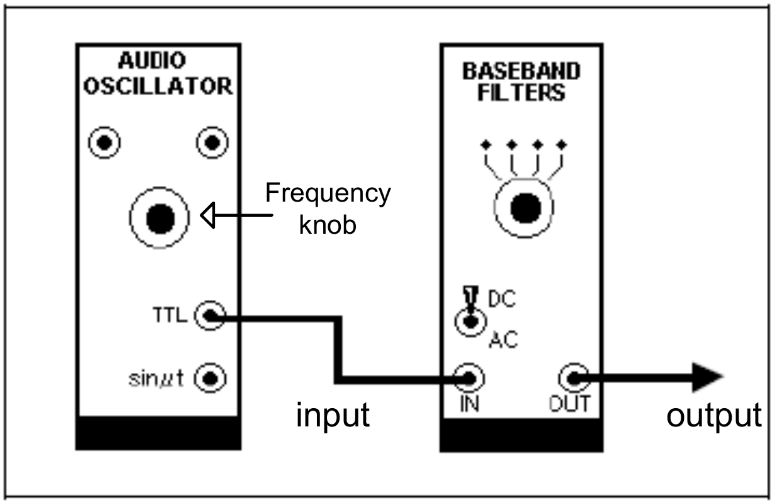

Figure 5: TIMS model of Figure 4

Both traces should now be displayed on the PicoScope at once. Adjust the timebase and the vertical ranges until two or three periods of the square wave are displayed and the traces are stable. Ask a tutor for a quick demonstration if you are not sure.

4.1.2 Tasks

- **Measure the period of the input square wave (CH-A) and check that the frequency you obtain agrees with the Frequency Counter reading.**

Adjust the horizontal time base of the PicoScope so that one or two transitions are displayed. Select **Channel 3** of the Baseband Channel Filters .

- **Observe and sketch the response to a single step in your exercise book.**

When the response to a step excitation is isolated in this way, so that it does not overlap the responses to neighbouring transitions, it is the step response of the channel.

Using the same setup, display the step response for Channel 2. Note the oscillations and the long settling time to the steady state value.

- **Observe and record the step response of Channel 2 in your exercise book.**

- **Measure and compare the time delays of the response for Channel 2 and Channel 3.**

Take the reference point for the delay to be 50% of the steady state value.

- **Measure the rise time of the Channel 3 response.**

Take the rise time to be the time taken to go from 10% to 90% of the steady state value

Checkpoint 1

Show a tutor your two sketches, with the delay marked on each and the rise time marked on the Channel 3 sketch. From your sketches, which channel rises faster? What does that tell you about the range of frequencies it passes?

4.2 Pulse response of a system

An isolated pulse $p_T(t)$ can also be used to characterise the system. The pulse at the SYNC output of the **Sequence Generator** serves as the input. The block diagram and the TIMS model of the setup are shown in Figure 6 and Figure 7.

4.2.1 Procedure

1. Connect the **Audio Oscillator** TTL output to the TTL CLK input of the **Sequence Generator**
2. Connect the **Baseband Channel Filters** input to the SYNC output of the **Sequence Generator**
3. Set the clock frequency to 1100Hz with the knob of the **Audio Oscillator**
4. Select **Baseband Channel Filters** **Channel 3**
5. Connect the input, $u(t)$, to the filter (SYNC) to CH-A and the filter output, $y(t)$, to CH-B

The input should now be a periodic train of widely separated pulses. Adjust the scope time base so that only one or two pulses are displayed. You may have to adjust your Trigger settings.

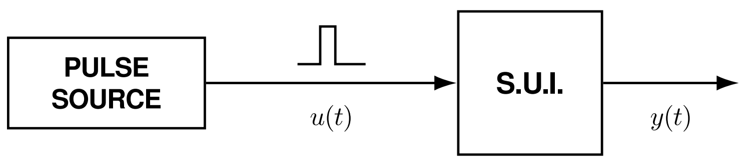

Figure 6: Block diagram of the pulse input

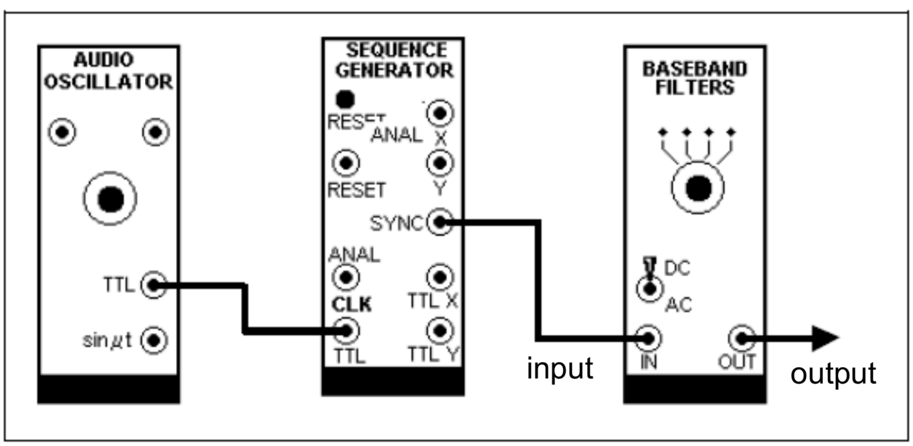

Figure 7: TIMS model of Figure 6

4.2.2 Tasks

▶ **Observe and sketch the channel's response in your exercise book.**

The output is a delayed copy of the input. Increase the clock frequency to 1600Hz and observe how the pulse width τ and pulse spacing change. As the frequency increases further, the flat top of the pulse becomes shorter and eventually disappears.

- ▶ **Record the clock frequency at which the flat top disappears.**

Past that frequency the shape of the output stays the same and only its magnitude falls. Once the pulse width τ is short compared with the time scale on which the channel responds, the input $u(t) = p_\tau(t)$ gives

$$y(t) = \int_{-\tau/2}^{\tau/2} h(t-\sigma)\mathrm{d}\sigma \approx \tau h(t),$$

so the output has the shape of the impulse response scaled by τ. Shrinking τ leaves the shape alone and reduces the amplitude, which is what you observe.

- ▶ **Without changing the setup, measure the delay from the peak (middle) of the output pulse, at the impulse response state, and compare it with the delay of the Channel 3 step response measured in Section 4.1.**

Discussion question 1

Graphically differentiate your Channel 3 step response and compare the result with the pulse response, paying attention to time alignment. What similarities do you observe?

Checkpoint 2

Show a tutor your pulse response for Channel 3 and the clock frequency at which the flat top disappeared. Why does the output keep its shape but lose amplitude as the pulse is made narrower?

4.3 Sinusoidal input to a system

We now try to characterize the system with a sinusoidal input. The block diagram of the setup is shown in Figure 8.

4.3.1 Procedure

1. Connect the **Baseband Channel Filters** input to a yellow output socket on the **Audio Oscillator**, as shown in Figure 9, so that the input is $u(t) = A\sin(\omega t)$.
2. Select **Channel 3**.
3. Starting at a low frequency, display the **Baseband Channel Filters** output and the input
4. Take frequency readings from the PicoScope or by connecting the yellow output socket of the **Audio Oscillator** to the ANALOG socket of the **Frequency Counter**.
5. Increase the frequency over the available range and observe the effect on the amplitude of the output signal
6. Take readings across the range, for example at 200Hz, 300Hz, 900Hz and so on up to 6000Hz.
7. Select Channel 2 and repeat the readings at the same frequencies.

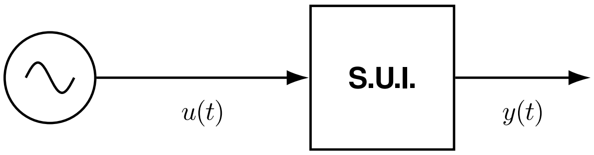

Figure 8: Block diagram of the sinusoidal input

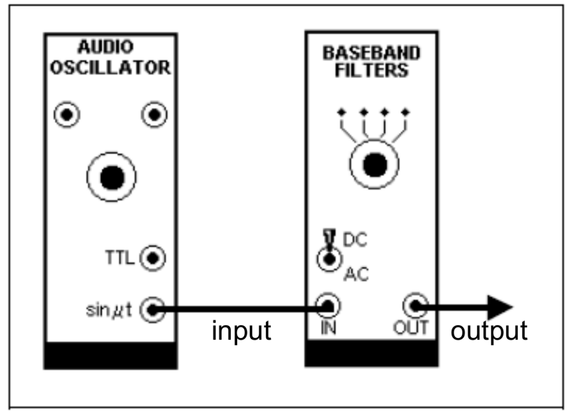

Figure 9: TIMS model of Figure 8

4.3.2 Tasks

- **Record the frequency and the peak-to-peak amplitude of the output in a table of the following form, for Channel 2 and Channel 3.**

Frequency (Hz)	V_{pp} **CH2 (V)**	V_{pp} **CH3 (V)**

- **Plot amplitude against frequency for both channels, and note the features of the graph. Consider using log scales.**

Discussion question 2

In Section 4.2, narrower pulses produced smaller output amplitudes. Discuss whether the reduction in sinusoidal output amplitude at higher frequencies can be explained by the same physical mechanism.

Checkpoint 3

Show a tutor your completed table of amplitude against frequency for both channels, and answer Discussion question 2. The plot can be finished after the lab.