TIMS: Introduction to the Instrument

Modules: Audio Oscillator, Speech, Adder, Wideband True RMS Meter, Digital Utilities

1 Displaying a Signal on the PicoScope

1. Turn on TIMS.
2. Computer: **`Start > All Programs > Pico Technology > PicoScope 6`**
3. Connect the 100-kHz *sin* output on Master Signals panel to a Buffer Amplifier input and that Buffer Amplifier's output to input port A1 of the PC-Based Instruments Inputs panel. Make sure the A1/A2 toggle switch is in the up (A1) position.
4. On the Capture Setup Toolbar, set the horizontal scale to 10 μs/div.
5. Set the Channel-A vertical scale to ± 5 V.
6. Flip the A1/A2 toggle switch on the PC-Based Instrument Inputs panel to the down (A2) position. You should observe that the 100-kHz sinusoid has been replaced on the display with a signal that is close to 0.
7. Move the patch cord that connects the Buffer Amplifier to the PC-Based Instruments panel from input port A1 to input port A2. The 100-kHz sinusoid should reappear on the display.
8. Move the patch cord from the Buffer Amplifier back to input port A1 and flip the toggle switch back to the up (A1) position. You should note that you can connect a signal to Channel A of the oscilloscope through either input port A1 or A2 but that the corresponding toggle switch must be in the appropriate position.

2 Continuous Capture and Stopped Modes for the Oscilloscope

1. Notice the red square and green triangle on the Trigger Toolbar. The green triangle means continuous capture is in effect. The red square means stopped (frozen in time).
2. If you haven't made any changes yet in the Trigger Toolbar, the signal display will be unstable. That's because we have continuous capture but are not properly triggering.
3. Select *stop* (red square). Now you have a frozen display, but at what cost?
4. Adjust the gain knob of the Buffer Amplifier. Notice that the oscilloscope display does not change. In stopped mode, the oscilloscope ignores any new signal information. This is generally unacceptable. If the signal changes, we want the oscilloscope to display the current signal conditions.
5. Select *continuous capture* (green triangle). The signal display will be unstable.
6. Adjust the gain knob of the Buffer Amplifier and notice how the new amplitude of the signal is immediately reflected in the oscilloscope display.

3 Triggering the Oscilloscope

1. On the Trigger Toolbar, the trigger mode has been, up till now, *None*. Change that to *Auto*. Hopefully, the signal display is now stable. If it is not stable, the next couple of steps will, hopefully, make it stable.
2. Make sure the trigger source (indicated on the Trigger Toolbar) is A. This means that triggering is based on the signal on Channel A.
3. Notice the yellow marker on the display. This marker shows the location of the trigger point.
4. Make sure that the trigger level on the Trigger Toolbar is set to 0 V.
5. On the Trigger Toolbar, change from triggering on a positive slope to triggering on a negative slope. Notice how the signal shifts horizontally in response. The trigger point should now correspond to a negative slop of the signal.
6. Change back to a positive slope for triggering.
7. Change the trigger level from 0 V to a few different positive values. Notice how the signal shifts horizontally in response. The trigger point will be at the trigger-level voltage.
8. Set the trigger level to a value well above the amplitude of the sinewave. The signal display will become unstable because you are asking for the impossible: to trigger at a level that is never reached by the signal.
9. Return the trigger level to 0 V. The signal display should become stable again.
10. Set the trigger source to Ext. The signal display should become unstable because you are not supplying an external trigger source.
11. Return the trigger source to A. The signal display should become stable again.

4 Frequency Counter

1. Insert the Audio Oscillator module into TIMS.
2. Connect the Audio Oscillator analog output to the analog input of the Frequency Counter.
3. Adjust the knob on the Audio Oscillator for approximately 4.5 kHz.
4. Experiment with the three different gate times for the Frequency Counter: 0.1 s, 1 s, and 10 s. You should form the opinion that a gate time of 0.1 s has the advantage of quick measurements that keep you essentially continuously informed about the frequency. On the other hand, a gate time of 10 s provides a more accurate measurement. A gate time of 1 s represents a compromise.
5. Remove the Audio Oscillator signal from the Frequency Counter, and instead connect one of the 100-kHz sinusoids from the Master Signals panel to the analog input of the Frequency Counter. Experiment with different gate times for this 100-kHz sinusoid. You should observe that this sinusoid is more stable in frequency than was the sinusoid from the Audio Oscillator. This is because the Master Signals panel employs a better quality (and more expensive) oscillator than does the Audio Oscillator module. But the Audio Oscillator does have the advantage that you can adjust its frequency (within limits).

5 Two Oscilloscope Channels

1. Up till now, Channel B has been off. In other words, there has been no Channel B display. On the Channel Setup Toolbar, change the vertical scale of Channel B from *off* to ±5 V. Connect the 100-kHz *cos* output on the Master Signals panel to Channel B (using either input port B1 or B2, with the toggle switch in the appropriate position).
2. Connect the 100-kHz *sin* output to Channel A, so there is a 90° phase difference between the sinusoids on Channels A and B. Even in continuous capture mode, the display should be stable for both the Channel-A and Channel-B sinusoids. This is possible because both sinusoids have the same frequency.
3. Change the trigger source from A to B. You should find that both signals shift horizontally, but that the display stabilizes after that shift. The yellow marker is now on the Channel B signal. The Channel-A sinusoid is stable, even though you are using the Channel-B sinusoid as the trigger source, because both sinusoids have the same frequency.
4. Replace the sinusoid that was on Channel B with a 4.5-kHz sinusoid as provided by the Audio Oscillator. On the Capture Setup Toolbar, set the horizontal scale to a suitable value, so that you get a nice display of cycles for both the 100-kHz and 4.5-kHz sinusoids.
5. Try using Channel A and then Channel B as the trigger source. You should find that you can get a stable display of one sinusoid or the other, but not both at once. This is because these two sinusoids have unrelated frequencies.
6. Select stop (red square). This freezes time, of course, but at least you have a still image of the two sinusoids to study. Of course, if a signal changes after the display has been stopped, that change will not be reflected in the display until you return to continuous capture mode (by selecting the green triangle). Generally speaking, we want to remain in continuous capture mode. Stopping the display is a last resort for when you are otherwise unable to stabilize the signal display by proper triggering.

6 TTL Signal

1. Connect a 100-kHz sinusoid on Channel A and a 100-kHz TTL signal on Channel B. (Both signals are available on the Master Signals panel.) Adjust the horizontal scale to a suitable value. Use the Channel-A sinusoid as the trigger source. You should observe that a TTL signal is a bi-level signal, and the two levels are 0 V and 5 V.
2. Change the trigger source to the TTL signal on Channel B. Set the trigger level for 0 V. The signal display will now be either unstable or perhaps quasi-stable but jittering a lot. The reason for the jitter or instability in this display is that you are asking that triggering occur at a positive-going zero crossing (assuming that the triggering is still set for a positive slope). Where's the positive-going zero crossing in a TTL signal? In principle, a TTL signal only has two values (0 V and 5 V) plus sharp transitions between those two levels, so there is no zero crossing. In practice, there is some variability about these two levels. The variability explains why your signal display is perhaps not totally unstable.
3. Change the trigger level to 2 V (still keeping the TTL signal on Channel B as the trigger source). Now the signal display should be stable. When triggering on a TTL signal, the trigger level needs to be greater than 0 V (and also less than 5 V).

7 DC Voltage

1. Connect GND (ground) from the Variable DC panel to Channel A. This should be 0 V. Turn off the Channel-B display.
2. Replace GND on Channel A with the DC output of the Variable DC panel.
3. Experiment with different DC output levels from the Variable DC panel. You should find that you can get between about -2.5 V and $+2.5$ V. When the Variable DC knob is in the middle of its range of motion, so that the line on the knob is vertical, the output is approximately 0 V. Counter-clockwise from that middle position gives a negative voltage, and clockwise from that middle position gives a positive voltage.

8 Audio Signal

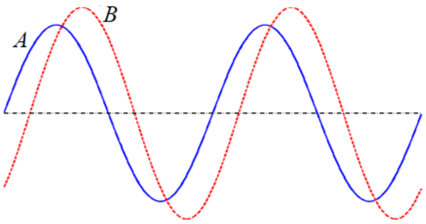
1. Insert the Speech module into TIMS.
2. Connect the Speech module’s CH 1 play output to the A input of the Headphone Amplifier panel. The Speech module’s CH1 toggle switch should be in the play position.
3. Insert the headphones jack into the Headphone Amplifier panel. Before putting the headphones to your ears, adjust the volume knob on the Headphone Amplifier panel for a reasonable volume. Then listen to whatever was last recorded on CH 1 of the Speech module.
4. You can (and should) record over the old CH 1 audio. You can do this by flipping the toggle switch to the record position. You can speak or play recorded music (from another device) into the microphone embedded in the Speech module. After you are done recording, flip the toggle switch back to play.
5. Connect the Speech module’s CH 1 play output to Channel A (of the PicoScope). The Speech module’s toggle switch should be in the play position.
6. On the Capture Setup Toolbar, set the horizontal scale to 100 ms/div. This signal should look very irregular (that is, random). There is no hope of stabilizing this signal display while in continuous capture mode. This helps explain why we use sinusoids and other periodic signals extensively while designing and testing communications equipment, even though message signals in applications are much more likely to be irregular (that is, random). We test our equipment the convenient way, using periodic message signals. But the final test is typically done with a more realistic message signal, such as an audio signal.

9 Relative Phase of Two Sinusoids Having a Common Frequency

We will use the PicoScope to measure the phase difference between two sinusoids having the same frequency. Table 1 lists a procedure for measuring the phase difference between two sinusoids of common frequency. As part of this procedure, you must determine the period T; this is the reciprocal of the frequency.

Table 1: Procedure for measuring phase difference of two sinusoids

1. For best accuracy, use AC coupling for both channels of the oscilloscope.
2. Select one positive-going zero-crossing for each sinusoid. These two positive-going zero-crossings should be separated in time by no more than one-half the period. Place a time ruler on each of the two positive-going zero-crossings. (To create a time ruler, use the mouse pointer to drag a little square from the lower left corner of the PicoScope display.)
3. Measure the time difference Δt between these two positive-going zero-crossings. (You'll do this with the time rulers.)
4. From Δt and the period T, calculate the absolute value of the phase difference in radians:
$$2\pi \frac{\Delta t}{T}$$
5. Indicate which sinusoid leads and which lags.



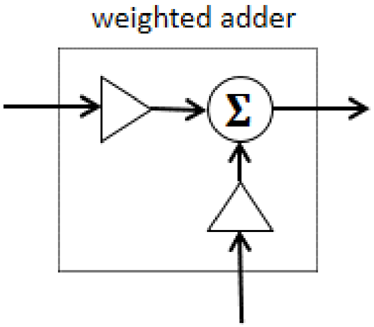
We should be clear about what it means for one sinusoid to lead or lag another. If the positive-going zero-crossing of sinusoid *A* is to the left of the positive-going zero-crossing of sinusoid *B*, as shown in the example plot above, then *A leads B*. That *A* leads *B* can be understood as follows: The sinusoid *A* reaches a reference phase (such as a positive-going zero-crossing) earlier than does sinusoid *B*. Equivalently, we say that *B lags A*. For these definitions to be useful, it is essential that $\Delta t \leq T/2$. If this inequality does not hold, then you need to reselect at least one positive-going zero-crossing.

Channel A: 100-kHz *cos* from the Master Signals panel
Channel B: 100-kHz *sin* from the Master Signals panel

Use the procedure outlined above to measure the phase difference between these two sinusoids.

10 Sum of Two Sinusoids

The module called Adder is actually a weighted adder. That is, if the inputs are $x_1(t)$ and $x_2(t)$, the output is $y(t) = G_1x_1(t) + G_2x_2(t)$. This fact is depicted below; each input of the Adder experiences a gain before passing into a true summer. Please note that the gains are implemented *inside* the Adder module; this diagram does not include any external amplifiers. The weighting factors G_1 and G_2 are adjusted with knobs on the front panel of the Adder module. Both G_1 and G_2 are negative. Dialing the G_1 knob clockwise increases its absolute value, but G_1 remains negative, and similarly for G_2.



The Master Signals panel has an analog 2-kHz sinusoid. The frequency of this sinusoid is not exactly 2 kHz; it is actually 100 kHz divided by 48. Measure this frequency with the Frequency Counter.

We want to add a 100-kHz analog sinusoid and a $(100/48)$-kHz analog sinusoid. The contribution of each to the output should be 1 V rms. Use the procedure of Table 2 to do this. Here $X = 1$ V rms. Neither of these sinusoids has a DC bias, so either AC+DC or AC coupling for the Meter is okay. For best accuracy, the Meter's range should be set to 2 V (rms).

Table 2: Procedure for adding two sinusoids, each contributing X volts rms to the sum

1. Connect the Adder output to the Wideband True RMS Meter. The Meter's input coupling and the range should be set appropriately.
2. Connect one sinusoid to the top input of the Adder. No signal should, for the time being, be connected to the bottom input.
3. The top gain knob on the Adder should be adjusted until the Meter reads X volts rms. This is the contribution of the "top" sinusoid to the Adder output.
4. Disconnect the "top" sinusoid from the Adder.
5. Connect the other ("bottom") sinusoid to the bottom input of the Adder.
6. The bottom gain knob on the Adder should be adjusted until the Meter reads X volts rms. This is the contribution of the "bottom" sinusoid to the Adder output.
7. Reconnect the "top" sinusoid to the top input of the Adder.
8. Both sinusoids should now be connected to the Adder. If this procedure has been done correctly, each sinusoid makes the same contribution (X volts rms) to the Adder's output. The Meter may now be disconnected from the Adder's output.

Place the output of the Adder, which should now equal the sum of a $(100/48)$-kHz sinusoid and a 100-kHz sinusoid, on Channel B of the oscilloscope. Set the timebase to 50 µs/div. Initially set the trigger source to *A*. Set the oscilloscope to trigger on positive-going zero-crossings. You should find that you don't get a stable display. If you look at the composite waveform, you will see that there are multiple positive-going zero-crossings even within one period of the composite signal. For a stable display, we need there to be just a single time instant within each period of the signal for which the triggering conditions are met (a positive-going zero-crossing, in this case).

There is a general oscilloscope rule that we must observe if we wish to stabilize a display involving two sinusoids. This rule is applicable whenever two sinusoids are present. The two sinusoids can be summed and the composite signal applied to one channel of the oscilloscope, as we have in the present case. Or each sinusoid can be on its own oscilloscope channel (that is, one sinusoid on Channel A and the other on Channel B). Here is the rule:

A stable oscilloscope display involving two sinusoids can be achieved only if those two sinusoids are coherently related and the frequency of each is a whole-number multiple of the frequency of the trigger source.

In using the composite signal (on Channel A) as the trigger source, we violated the above oscilloscope rule. That composite signal does not even have a single, well-defined frequency (since it is the sum of two sinusoids of different frequencies). But there is hope. The two component sinusoids are coherently related. They both come from the Master Signals panel, where (internal to the TIMS instrument) they are both derived from a common oscillator.

We can stabilize this display with a better choice of trigger source. In this case, we can use as trigger source a periodic signal having a frequency of $(100/48)$-kHz. With such a trigger source, the 100-kHz sinusoidal component has a frequency that equals (the whole number) 48 times the frequency of the trigger source. And, of course, the $(100/48)$-kHz sinusoidal component has a frequency that equals 1 times the frequency of the trigger source.

Let us suppose that in this case we don't want a $(100/48)$-kHz sinusoid to appear on Channel B of the oscilloscope. We want only the composite signal to appear on the oscilloscope display. We can achieve this while also having an appropriate trigger source by using a TTL signal of frequency $(100/48)$-kHz as an *external trigger* source.

An external trigger source should always be a periodic signal, but it need not be a sinusoid. In fact, with the TIMS instrument we will generally get better results using a TTL signal, rather than a sinusoid, as the external trigger source.

There are two versions of the TIMS-301C instrument: an older version and a newer one. In the newer version, a $(100/48)$-kHz TTL signal, called 2 kHz TTL, is available on the Master Signals panel. In the older version, a $(100/48)$-kHz TTL signal is not available. With this older instrument, you can generate a $(100/48)$-kHz TTL signal from the $(100/12)$-kHz TTL signal (on the Master Signals panel), called 8.3 kHz TTL, using a divide-by-4 on the Digital Utilities module. The divide-by-4 circuit divides the frequency of a TTL signal by 4.

Apply a (100/48)-kHz TTL signal to the E (external trigger) port of the PC-Based Instrument Inputs panel and then select *Ext* for the trigger source on the PicoScope. Since the trigger source is a TTL signal, which is not designed for zero-crossings, a trigger level of 0 V is not appropriate here. Set the trigger level to 2 V. Hopefully, the Channel-A display of the composite signal is now stable with the oscilloscope in continuous capture mode.

Channel A: sum of 100-kHz and (100/48)-kHz sinusoids