Loadboard Design for TIA (TMU) and Tester Pins

Using a TIA (TMU) in a Tester

This application note illustrates how you can connect multiple device pins to both tester pins and time interval analyzer (TIA) channels to improve the timing accuracy of your tester and enable additional measurements that are not possible with your tester.

The time interval analyzers from Carmel Instruments can be used as a dedicated TMU (Time Measurement Unit). The NK732, NK734 and NK738 provide 2, 4, or 8 channels respectively in a single PXIe slot.

These TIAs have timing resolution of 2 ps without averaging and absolute overall timing accuracy of 10 ps. This application note shows how you can use run-time calibration to achieve accuracy of 5 ps.

Frequency measurements are much quicker with the NK73x Series because the 2 ps resolution translates into shorter total measurement duration to arrive at a certain resolution. For example, you can make a 1 ppm frequency measurement in 2 µs. Many testers require milliseconds to make this measurement. A 0.1 ppm measurement would take 10 times longer.

In a single 18 slot PXI chassis you can have up to 16 NK738 TIAs providing 128 channels. With the NK73x all the channels operate simultaneously, and the PXIe interface, which is PCIe Gen 2, allows extremely fast data transfers.

Accuracy

The NK73x Series has a specified overall timing accuracy of 10 ps.

High Frequency

Extend the frequency range of your tester to 6 GHz with the NK732 for frequency measurements (1.6 GHz with the NK734 or the NK738).

Throughput

The high timing resolution and PCIe interface translate into high throughput.

Jitter

Jitter measurements are useful down to 2 ps. Since the NK73x Series can make 20 million time measurements per second (every 50 ns), you can see dynamic variations in the timing of your device. Crosstalk and other reasons for jitter can easily be detected.

Duty Cycle

The TIAs can measure the frequency and the pulsewidth of the signal to an accuracy of 10 ps. From these measurements you can calculate the duty cycle. For example, at 100 MHz a 100 ps error in the pulsewidth is an error of 1% in the duty cycle.

Tester Calibration

You can easily "spot cal" specific pins of the tester and get total accuracy down to 10 ps.

How to Connect

Usually you need to connect the device pin to both a tester pin for DC measurements and to the TMU for the AC measurements.

Without Multiplexing

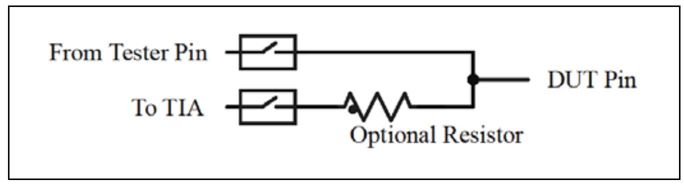

Figure 1: Per-Pin Connection

In Figure 1 above we show the simplest connection to the TIA and the tester which uses Form A (SPST) relays such as the Coto 9814. This method uses one tester pin and one TIA channel for each device pin. The 9814 is a good choice because it is a reed relay with 6 GHz bandwidth, fast switching (specified at 250 µs), and very long life of 1 billion operations (see below about avoiding "hot switching").

This arrangement with two Form A relays allows independent control of the switches and all connection combinations. For an output pin of a device under test (DUT) you can close only the tester pin relay for DC parametric measurements and only the TIA relay for AC measurements. For a DUT input pin you can connect to the tester only for the DC parametrics and to both the tester and the TIA for AC measurements where the tester is the driving source. In this situation the device pin should not be terminated because the NK73x Series have a fixed 50 Ohm termination. This termination resistor is connected to a programmable voltage.

The trace on the DUT side should go from the tester pin relay to the DUT and then to the TIA relay. Do not connect the two relays together near the relays as this would cause a stub.

If the fixed 50 Ohm input impedance of the NK73x Series is too low for the device you can either buffer the signal with an amplifier or just use a series resistor before the relay for the TIA ("Optional Resistor" in Figure 1) For example, if you use a 450 Ohm series resistor, the load on the device will be 500 Ohm and the signal voltage will be divided by 10. You will need to adjust threshold voltage settings on the TIA accordingly. The cable is still properly terminated with 50 Ohms as required and the signal integrity is preserved. The NK73x Series can measure signals down to 50 mV.

With 4:1 Multiplexing

For systems with a high pin count cost can be reduced by multiplexing. Figure 3 is a block diagram showing the switching required to connect 4 tester pins and 4 TIA pins. Figure 5 is an example layout pattern with all the traces on the top layer and all traces equal length. The result is the following:

- Each device pin requires 2 Form A relays and 1.5 Form C relays. The Coto 9814 is about $5 and the Coto 9852 is about $25 so the cost per pin is about $50.
- For a 128 pin system you will need 32 TIA channels, 32 tester pins and 448 relays at a cost of about $6,400 for the relays.
- The multiplexer part with the 3 form C relays has a tree structure. This structure has no stubs and since the 9852 relays are 50 Ohm, the impedance of the whole path is a clean 50 Ohm.
- The signal from the DUT to the TIA passes 3 relays. See the discussion below on risetime measurements for the expected degradation of the signal.
- You cannot measure time difference between pins that are on the same 4:1 multiplexer. You can assign the pins accordingly or you can make all measurements against a reference signal and compute the differences.
- Sometimes device pins must be loaded even if they are not measured. For example, when measuring the skew of a fanout buffer you cannot measure one pin at a time without loading all the other pins. In that situation you can eliminate the multiplexer for the tester pins and use one tester pin per device pin. You then use the tester to load the pins that are not measured.
- With careful planning of the order of tests you can reduce the amount of switching.

Measuring Across all Channels

The NK73x Series instruments allow time measurements between channels which are on different instruments (different PXIe slots). These measurements are specified with a lower absolute accuracy unless you are using the calibration techniques outlined below.

Measurements

Skew

This is the measurement of the time difference between two channels, usually running at the same frequency, although that is not a requirement for the TIA. The Time Interval function would be used. It measures the time from an edge on one channel to the following positive or negative edge on the other channel. The total accuracy of the measurement depends on the accuracy of the TIA plus the mismatch in the test setup including the cables. If the mismatch in the cable is to be calibrated out, it can be measured at test initialization time (usually done only once in the beginning of a batch of parts). Accuracies down to 10 ps can be readily achieved (see “Calibration” below).

Propagation Delay

TIAs can measure the propagation delay of digital logic directly. That is, you measure the actual propagation delay, not pass or fail. This can provide better yield and accuracy. The measurement is from the input pin (the “fly-by” signal) and the output pin.

Risetime and Slew Rate (High Speed Amps and Digital)

The accuracy of risetime measurements is affected by several factors. First and foremost is the bandwidth of the input of the instrument. The NK73x Series have an analog input bandwidth of 8 GHz, and an input risetime of 30 ps. You can reliably and accurately measure risetimes down to 30 ps. The input risetime affects the results by adding to the actual input signal risetime in a root-mean-square fashion.

$$result = \sqrt{ActualRisetime^2 + (30ps)^2}$$

You can correct the measurement as follows:

$$ActualResult = \sqrt{MeasuredResult^2 - (30ps)^2}$$

For example, if the actual risetime of a signal is 100 ps, then the instrument will report a result of 105 ps. This error can be corrected for specific test cases.

When using the 4:1 multiplexing in Figure 3, the risetime of the TIA input including the relays is (assuming 70 ps risetime for the 9814 relay and 85 ps for the 9852 relay):

$$TiaRisetime = \sqrt{(70ps)^2 + (85ps)^2 + (85ps)^2 + (30ps)^2}$$

$$= 142\ ps$$

You therefore correct the measurement result as follows:

$$ActualResult = \sqrt{MeasuredResult^2 - (142ps)^2}$$

For example, if the actual signal risetime is 500 ps the TIA will report a measurement of 520 ps. Using the formula above we correct it back to the 500 ps real value.

The degradation of the signal risetime due to the coaxial cables is minimal if you are using high quality cables and their length is less than 1 or 2 meters.

Another factor affecting accuracy is the accuracy of the voltage threshold settings. The NK73x Series are accurate to 5 mV (200 μV resolution).

Tristate Propagation Delay (Enable/Disable Time)

To measure the time to disable or enable a tri-state output pin it is usually required to terminate the pin to a load voltage through a resistor. The TIAs have programmable termination voltage but the resistor is fixed at 50 Ohm. This may require using the tester pin as a load and adding the optional buffer in Figure 3.

Alternatively, the enable and disable time can be measured using the tester pin if the accuracy on this measurement is less critical.

Buffer Amplifiers

If you need to use a buffer (shown as “Optional Buffer” in Figure 3), you can use a high bandwidth amplifier such as OPA659. This is possible for parts with risetimes >1 ns.

Layout

To reduce timing skew errors, the traces for all pins should be the same length. It is also important to keep the design symmetrical and to route all pins the same way. For example, if you have to use internal layers for some of the pins then you should use internal signals for all the pins. The number of vias and the trace lengths between vias should also be the same. This reduces any temperature drift.

Note that the signal delay through traces on the top and bottom layers of the board is different from the delay through internal layers. The dielectric thickness for all high speed signal layers should be the same. Trace delay is on the order of 60 ps/cm.

Of course, all the cables to the TIA should be of equal length.

Calibration

If the loadboard has equal length traces and you are using equal length cables you usually have less than 100 ps of skew between pins. To improve that you need to use one of the following techniques:

1. **Golden Device** – This method assumes that you have a device that you characterized on the bench using a test board with SMA connectors. Occasionally you use this device to calibrate the tester. In a production environment this usually means that you need to have multiple golden devices available in case one is damaged. Some of Carmel Instruments customers achieved 5 ps repeatability with this method.
2. **Special DUT Board** – If your system has a separate DUT board which connects to the loadboard, this method uses a special version of the DUT board which uses a signal from the tester and simply distributes it to all pins in parallel. To reduce the load on the tester pin you can use series resistors for each pin. For example, if you use 950 Ohm resistors you can distribute the signal to 16 pins and end up with a 62 Ohm load for the tester. If the tester signal is 6V amplitude then you will still get a 300 mV signal at each TIA input.
   Alternatively, you can use a splitter (such as the JEPS-16-1W+ from Mini-Circuits) and drive a square wave. The signal will only be divided by 4 (not by 16). The splitter is AC coupled so it has a minimum frequency spec. In the case of the JEPS-16-1W+ it is 5 MHz so 10 or 20 MHz would be good choices.
   The signal can also be buffered by a low skew clock buffer.
   Whichever method is used, you still need to characterize this special DUT board to get down to 10 ps or better accuracy.
3. **Signal swapping** – This method uses two form C relays to exchange the signal between two TIA inputs (Figure 2). By measuring the time difference between the two signals in both swapped and unswapped conditions you can determine the skew error of the TIA. This includes the skew error of the signal path from the relays to the TIA and the TIA itself. For example, assume that Signal 1 and Signal 2 have a skew of 100 ps where Signal 1 is earlier, and that the skew errors of Ch 2 of the TIA plus the cables from the relays is 20 ps. Ch 1 is the reference in this case so its skew error is 0. The 20 ps error for Ch 2 is subtracted from the result of a Time Interval measurement from Ch 1 to Ch 2.
   Now, if we connect Signal 1 to Ch 1 and Signal 2 to Ch 2 we will measure 120 ps. If we swap the signals we will measure 80 ps.
   Therefore, the average of the two measurements is the actual skew of Signal 1 and Signal 2, while the difference between the two measurements divided by 2 is the skew of the TIA.

Signal swapping has the advantage that it can be done at run-time. The disadvantage is that it requires an additional form C relay for every pin. It is therefore appropriate on a small number of channels. **Error! Reference source not found.** shows an example layout pattern with equal length traces.

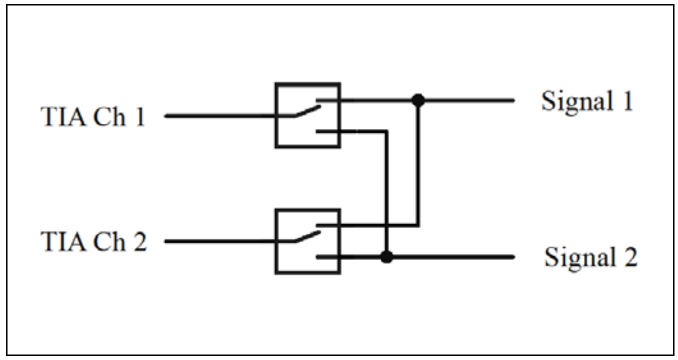

Figure 2: Signal Swapping

All skew measurements can be done across all TIA channels, even if they are on different instruments. However, measurements across instruments have a lower accuracy unless you use one of the calibration methods above, and the arming of measurements is less flexible.

Relays

Considerations when using relays:

- Throughput is reduced due to switching times ranging from 250 µs to several ms.
- Reliability – Life is specified from millions of operations to hundreds of millions. If your system switches a relay once every second, then you get 31 million switches per year. The 9814 relay specifies 1 billion operations while the 9852 is 100 million with a 10 mA current.
- Hot switching – The life of the relay is reduced if the signal is on during the switching. What matters is the current being switched, not the voltage.
- Power – The Coto 9814 requires 33 mA when closed, while the 9852 requires 45 mA. The system mentioned above with 128 pins connected through 4:1 multiplexing to 32 tester pins and 32 TIA pins requires 256 9814 relays and 192 9852 relays for a total current of 17A from a 5V supply. The actual worst case is lower because not all relays are on at the same time, especially in the multiplexer.

System Diagnostics

The loadboard and all the cabling can be verified in the system without a DUT installed by connecting the tester pins to the TIA inputs and measuring the input resistance of the TIA and the timing of all the pins of the tester. You can also verify the termination voltage of the TIA with the tester.

You can measure all the channel delays for all the pins on each system and use that information to verify that all the cables are OK. The system will be able to detect a situation where someone replace a cable with one of significantly different length.

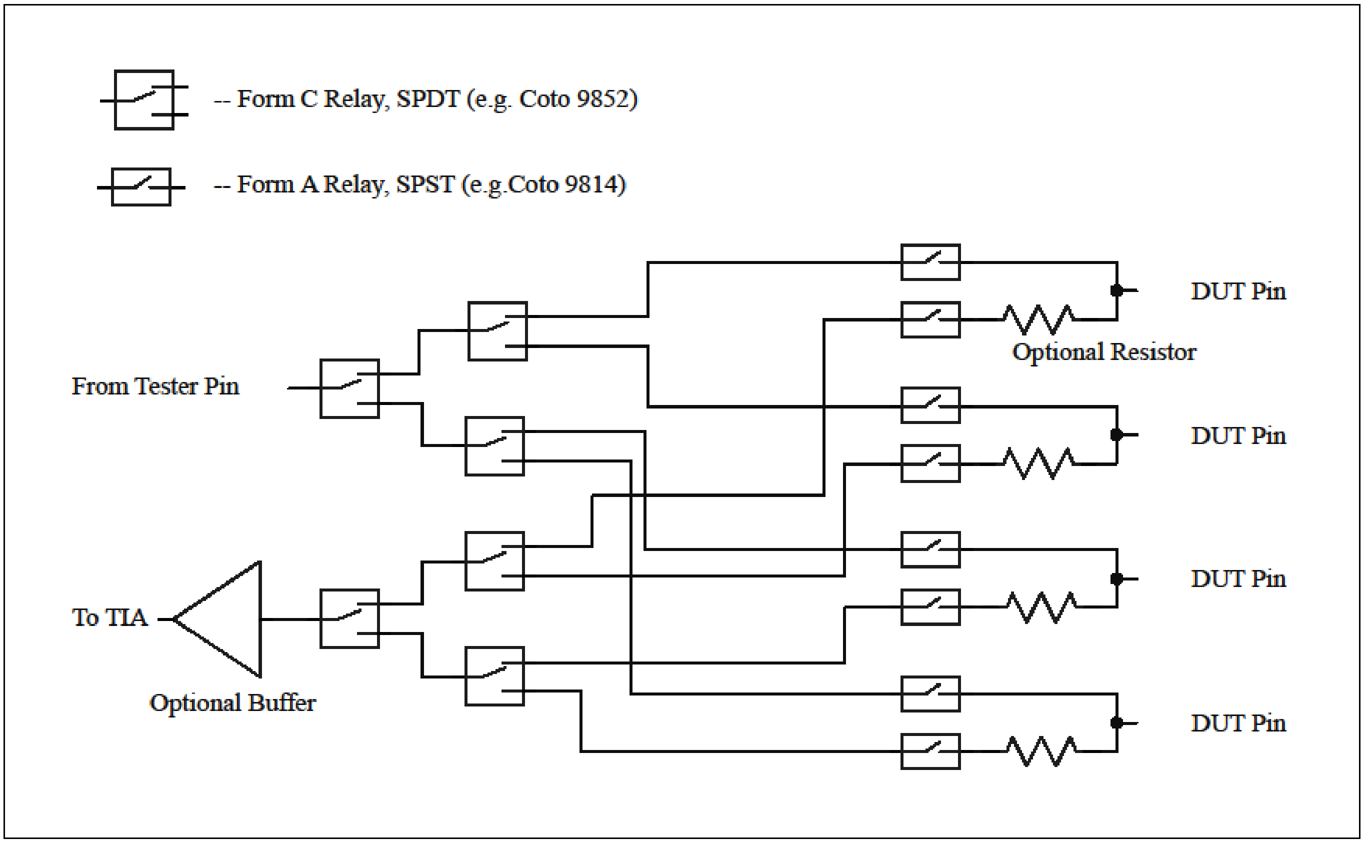

Figure 3: Block Diagram with 4:1 Multiplexing

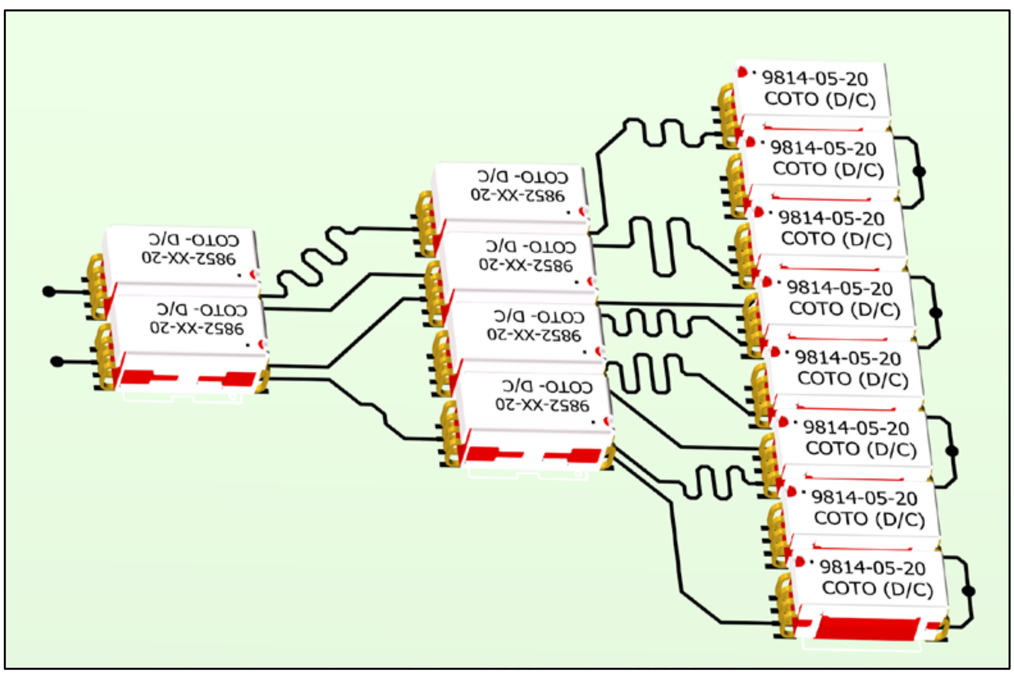

Figure 4: Simulated Board Picture

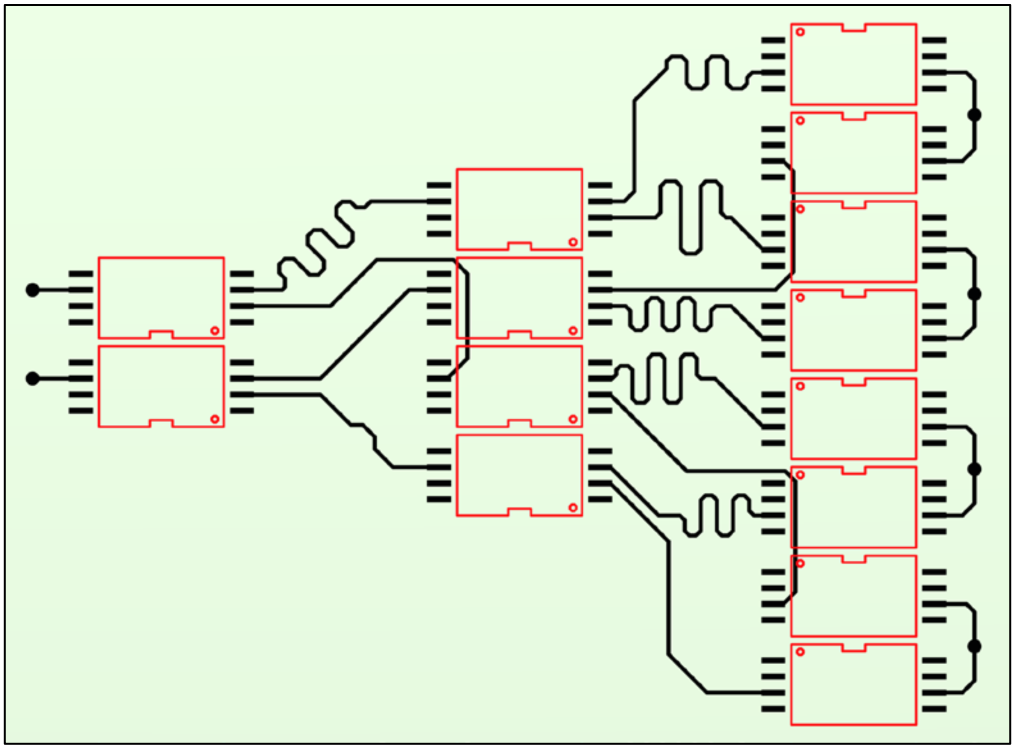

Figure 5: 4:1 Layout Pattern (All Traces are on Top Layer)

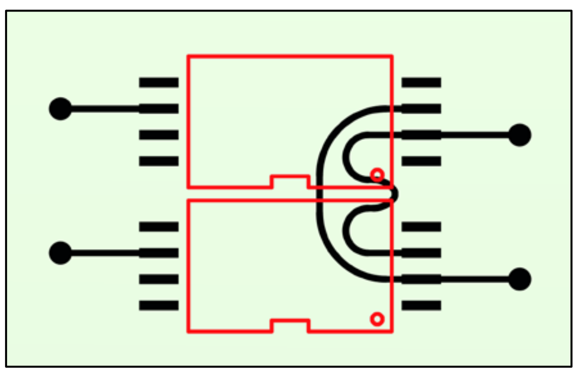

Figure 6: Signal Swapping Layout