APPLICATION NOTE CX5009

This document discusses the issues that must be considered when performing high accuracy Time Error measurements. It also offers some tips on how to ensure the uncertainty due to cable delays is minimized.



Managing the impact of

CABLE DELAYS

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Cable delays and managing their impact

1. Introduction

This paper discusses issues that need to be considered when performing high accuracy Time Error measurements, and includes some tips on how to ensure errors due to cable delay are minimized.

The delay of a 1m length of cable is approximately 4.9ns for optical cable, and 5.1ns for electrical. To perform high precision Time Error measurements, cable delays need to be considered carefully for each measurement set-up used. Appropriate values need to be configured for the cables connecting reference and measurement interfaces to ensure the correct compensation is applied by the measurement equipment, which in this discussion is Calnex Paragon-X.

By design, Paragon-X offers optional integration of PTP Master and Subordinate clock functions, which further minimizes potential error sources commonly associated with Time Error measurements.

2. Paragon-X compensation fields

The **Test Configuration** section in Paragon-X provides fields where cables, relevant to the configured set-up, can be accounted for. You can enter the delay associated with each cable¹.

a) PTP emulation mode configuration

*.	💒 🞾 🍽 R 🛛 💌 😋 🔍		1		
Start Up	<< Results	Test Setup	G.8275.1 Phase Profile	Calnex Master	< 1/1 > ×
Operating Mode	Device Configuration Master + Slave Two Masters			Mode: Multicast Connected Slave D-Rec Address Rate	Sync Ann Rate Rate
Setup Interface	Configure	pensation fields Calnex Paragon-X	Refin	@ 01 1b 19 00 00 00	
Master/Slave/GPS Emulation	Test Configuration Boundary Clock	Master 1 pps	Slave		
Measurements	DUT Ethernet 0 0		Carter 1		
Select Flow	cable (ns): 1pps Meas. cable (ns): 0 0 0 0 0 0 0 0 0			Calnex Slave	Rates
Configure Capture	Capture (* Master	Capture Address	Satur -	Connected Master D-Rec Address Rate	Sync Ann Rate Rate
Start Capture	C Slave C Rix on both	Port 1	Port 2		
Add Impairments/ Delay	Flow Filter Measurement	1 pps/ToD 2M/TI/E1			
Add Wander	Calibration	L.J.T.			
	Start			Link Status	ket
Packet Generation	Set capture flow filter			1 O GOOD F 2 O GOOD F	ACKETS
Statistics/ Results	Apply changes	Master + Slave		⊖ RefLock ⊖ 1PPS Ref ⊖	1PPS Meas

¹ When the 1pps output from Paragon-X is used to supply a reference to other equipment, the cable length compensation should be applied by the equipment terminating the reference signal.

b) 1588 capture mode configuration

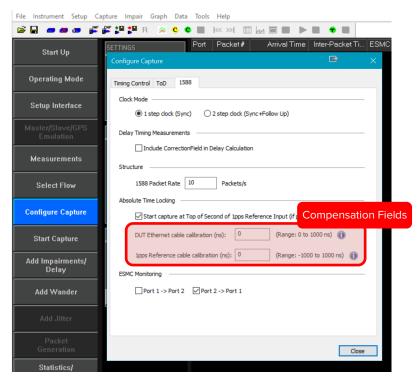


Figure 2

c) 1pps Time Error (Absolute) configuration

File Instrument Setup C	apture Impair Graph Data Tools Help
🗃 🖃 🛲 🍻 🍺	💒 🚼 R 🚿 🗘 🗢 🔳 📧 »I 💷 🗠 🔳 🕨 🖿 🗮 🕈 🔲
Start Up	SETTINGS Sampl Sample Period Time-Interval Error (T El Configure Capture 📼 🗙
Operating Mode	Timing Control ToD Sync-E Wander Ipps Time Error(Absolute)
Setup Interface	1pps threshold T I Limit 1.500 μs (Range: 0.005 μs to 50 μs)
Master/Slave/GPS Emulation	ST Cable input calibration Compensation Fields
Measurements	Reference: 0 ns (Range: -5000 ns to 5000 ns) 0 Measurement: 0 ns (Range: 0 ns to 5000 ns) 0
Select Flow	
Configure Capture	
Start Capture	FLC Pa
Add Impairments/ Delay	Pk Fk Fk
Add Wander	Fr.
Add Jitter	
Packet Generation	Close

3. Which cables impact results?

When using Paragon-X, depending on the configuration and measurement being performed, the following cables need to be considered.

1pps measurement mode

Consider the cable length from the 1pps output of the Device-Under-Test (DUT) to Paragon-X's 1pps measurement port. Figure 4 shows the user interface of the Paragon-X with the 1pps measurement cable highlighted.

	💒 🎾 🏦 R 🔗 C 📀		1					
Start Up	<< Results	Test Setup	G.8275.1 Phase Profile	•	Calnex M	aster	< 1/1	> x
Operating Mode	Device Configuration Master + Slave Two Masters GPS Emulation				Mode: Multicast Connected Slave Address	D-Req Rate	Sync Rate	Ann Rate
Setup Interface	Configure	GPS Emulation Calnex Paragon-X	Refin		@ 01 1b 19 00 00 00			
Master/Slave/GPS Emulation	Test Configuration Boundary Clock	Master 1 pps	Slave					
Measurements	DUT Ethernet 0							
Select Flow	cable (ns): 1pps Meas. cable (ns): 0 0 0 0 0 0 0 0 0	1pps meas			Calnex :	Slave	F	Rates
Configure Capture	Capture	Capture Capture	Senter		Connected Master Address	D-Req Rate	Sync Rate	economic e
Start Capture	C Master C Slave C Rix on both	Port 1	Port 2					
Add Impairments/ Delay	Flow Filter Measurement	1 pps/Ti 0 2M/Ti/EI	Î					
Add Wander	Calibration							
Add Jitter	Start				Link Stat	us Rx Pade	et	
Packet Generation	Set capture flow filter				1 \Theta 🛛	GOOD PA	CKETS	
Statistics/ Results	Apply changes	Master + Slave			⊖ RefLock ⊖ 1PPS Re	f \varTheta 1	LPPS Me	as

Figure 4

Figure 5 below shows the compensation field for the 1pps measurement.

File Instrument Setup Cap	iture Impair Graph Data Tools Help
** *	
Start Up	SETTINGS Arrival Time Msa Tvoe ToD Messaae
Operating Mode	Configure Capture
Setup Interface	T lipps threahold
Master/Slave/GPS Emulation	51 Cable input calibration
Measurements	Reference: 0 ns (Range: -1000 ns to 1000 ng) 0 Measurement: 0 ns (Range: 0 ns to 1000 ng) 0
Select Flow	Compensation Field
Configure Capture	
Start Capture	
Add Impairments/ Delay	
Add Wander	
Add Jitter	Close
Packet Generation	
Statistics/ Results	

1588 measurement mode

a) PTP emulation configuration

Consider the cable connecting the egress 1588 from the DUT to the emulated subordinate clock in Paragon-X i.e., connected to Paragon-X Port 2, and the cable connecting the 1pps output from the DUT to the Paragon's 1pps measurement input. See Figure 6 below.

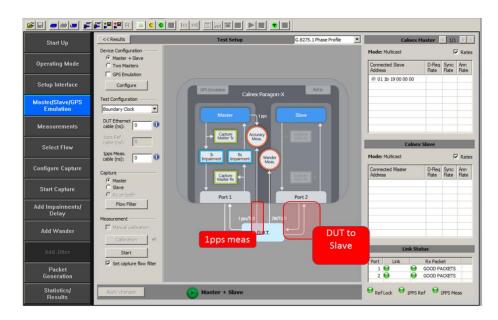


Figure 6

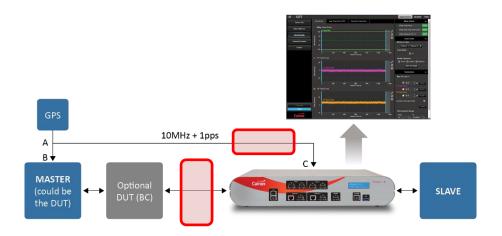
b) Master configuration

Consider the cable connecting the egress 1588 from the DUT to Paragon-X Port 2, and the cable connecting the 1pps reference to the Paragon's 1pps reference input. See Figure 7 below.

File Instrument Setup Capt	ure Impair Graph Data Tools	Help			
* • • • • *	20 10 R 🙍 C O				
Start Up	<< Results	Test Setup	G.8275.1 Phase Profile	Calnex Ma	ister
	Device Configuration			Mode: Multicast	✓ Rates
Operating Mode	C Two Masters			Multicast / Slave Address	D-Req Sync Ann Rate Rate Rate
	GPS Emulation		1pps ref.	Address	nale nale nale
Setup Interface	Configure	GPS Emulation Calnex Paragor	Ref In		
Master/Slave/GPS	Test Configuration		^		
Emulation	Master Test	Master	Slave		
Measurements	DUT Ethernet o				
Select Flow	1pps Ref. cable (ns): 0		→ Capture Slave Tx	Calnex S	lave
Select Flow	1pps Meas, cable (ns): 0			Mode: Multicast	Rates
Configure Capture	Capture			Connected Master	D-Req Sync Ann
	C Master		Capture Slave Rx	Address a0 00 00 00 00 01	Rate Rate Rate
Start Capture	 Slave C Rx on both 		Port 2		
Add Impairments/	Flow Filter	DUT to			
Delay	Measurement	Slave			
Add Wander	Manual calibration	Master			
Add Jitter	Calibration	t t	Frequency • 1pps	Link Statu	IS
Add Jitter	Start Set capture flow filter		0	Port Link	Rx Packet
Packet Generation	Jet capture now inter				NO PACKETS NO PACKETS
Statistics/ Results	Apply changes	🕑 Slave		\varTheta Ref Lock 🛛 \varTheta 1PPS Ref	1PPS Meas

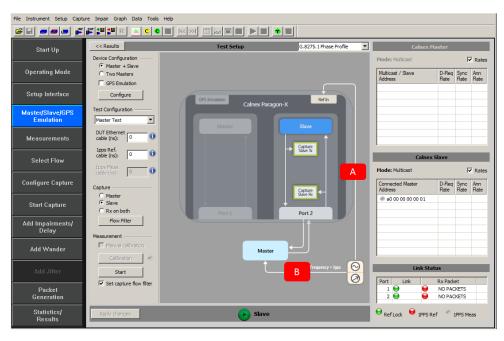
c) Thru mode configuration

Consider the cable connecting the upstream network/DUT to Paragon-X i.e., connected to Port 1, and the cable connecting the 1pps reference to the Paragon 1pps reference input.



1pps reference

When locking to an external time reference, consider the cable connecting the Reference source to the Paragon-X 1pps Reference input port. See A in Figure 8 below.





Note that if the 1588 master in the test set-up does **not** provide compensation for cable delay, the length of the cable from the Reference to the 1588 master under test (B) should be subtracted from the cable length between the reference and Paragon-X (A). A negative value should be entered in the field when the cable to the 1588 master is longer than that to Paragon-X. Refer to the *Complex Cabling of the 1pps Reference* section later in this document on for further information.

4. Determining the delay value for a cable

An optical cable typically creates a delay of 4.9ns per metre, while an electrical cable is around. 5.1ns per metre. Wherever possible, very short cables should be used as these will reduce the total delay as well as the uncertainty in the delay estimation. If long cables are used and/or it is important to minimize uncertainty, it is suggested that a test is performed using Paragon-X to determine the *actual* delay produced by the specific cable.

Ethernet cables (Optical or Electrical)

a) Enable Master/Slave Emulation mode of Paragon-X then connect Port 1 to Port 2 with the cable to measured. See Figure 9.

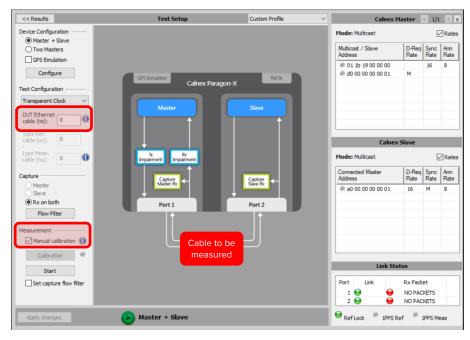
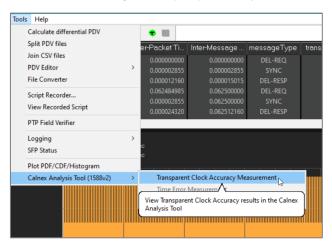


Figure 9

b) In the Master/Slave/GPS Emulation screen, select *Transparent Clock* in the Test Configuration and any endto-end profile (e.g. G.8275.1) depending on available options. Check "Manual Calibration" checkbox and ensure the DUT Ethernet Cable (ns) value is set to "0". Start PTP emulation, then perform a capture for 30s, stop the capture, and launch the Calnex Analysis Tool (CAT) for Transparent Clock Accuracy Measurement.



c) Record the Mean [ns] value for the Fwd Latency and Rev Latency metrics shown below in Figure 11.

TEX I								Application System He
	_	1						Application System He
Select File	Time Error	Time Error (Filtered)	Avg Time Error (cTE)	Dynamic Time Error				Mask Status
Select Metrics	🛓 2Way Time	е Еггог						No metrics with active masks
301001 1100103	ê					Min [ns]: 0.5, Max [ns]:).5, Mean [ns]: 0.5 📝	
View Results	2Way Time	Time Error						
	₽ .	5 1	10 15	20 25	30	35 40	45	Marker 1 Marker 2 💼
Generate Report	the T1 Time F	TTOP		Elapsed Time (s)				Chart & Zoom mode
	[11 Time Ei					Min [ns]: -63, Max [ns]: -	62 Moon (no): 62	
Export	ू -60 - T1 Ti	me Error				Min (ns)03, Max (ns)	os, mean (ns): -os	
	Berlin							
	f .	5 1	10 15	20 25 Elapsed Time [s]	30	35 40	45	- Errors & Labers & Markers
	🔟 T4 Time E	rror						Autohide Threshold Statistic
	[월 74 Time Ei 문 70 - 별 <u>74 Tim</u>					Min (ns): 64, Max (ns):	64 Mean (ns): 64	Save As Image
	ម្ពី T4 Ti	me Error						
	<u> </u>							ā
		5 1	io 15	20 25 Elapsed Time [s]		35 40	45	Elapsed Time
	🖿 Fwd Laten	cy						Parameters
	⁷⁰]					Min [ns]: 63, Max [ns]:	63 Mean (ns): 63 🚽	Max TE Limit +/-
	60 - Fwd L							2Way Time Error:
	- 08 Ē							
	0		10 15	20 25 Elapsed Time [s]		35 40	45	μsμsμp
	📥 Fwd CF D	elta						T1 Time Error:
						Min Ins): 0 Max fr	is]: 0, Mean [ns]: 0 📝	🔲 🛄 🛄 💭 💭 💭 💭 💭 🔲
	Fwd (CF Delta				min (no), v, mux (r		
	Fwd C							
			10 15	20 25		35 40	45	
	🗠 Rev Laten	011		Elapsed Time [s]				
		cy						
	<u> </u>	atency				Min [ns]: 64, Max [ns]:		
	9 60	5 1	10 15	20 25	30	35 40	45	
				Elapsed Time [s]				
Calculate	📙 Rev CF De	elta						
	E Rev C	D-H-				Min [ns]: 0, Max [r	is]: 0, Mean [ns]: 0 📝	
100%	Rev C	CF Delta						
	5	5 1	10 15	20 25	30	35 40	45	
Calnex	, v		10 15	20 25 Elapsed Time [s]				

Figure 11

d) The Paragon-X has a 5ns measurement resolution, in order to achieve the most accurate estimate of the measured cable delay use both measurement points by performing the calculation below:

(Fwd Latency + Rev Latency) / 2

Example: (64+63)/2 = 63.5ns

The result should be rounded to the nearest whole nanosecond then entered into the Paragon-X GUI.

1pps cables

Configure Paragon-X in Master/Slave mode and connect the Paragon-X 1pps reference output (from the lower Aux port on the front panel) directly to the 1pps measurement input (with the cable intended for use in the measurement. Early versions of Paragon-X require user selection of the 1pps output on the Lower AUX port via the Paragon-X GUI.

Start a 1pps accuracy measurement. The measured result gives the delay associated with the cable.

5. Complex cabling of the reference 1pps

When an external reference is being supplied to Paragon-X and to the source of the 1588, when that source is not configured to compensate for the delay of that 1pps reference cable, then the difference in the cable length should be entered.

1pps cable from GPS/PRTC to Paragon-X =	A m
1pps cable from GPS/PRTC to GM =	Вm
Cable compensation required =	(A-B) m

The calculated cable compensation value should be converted to nanoseconds, and, depending on the measurement type, entered in the *1pps Reference cable calibration (ns)* field shown in Figure 13, or the *1pps Ref. cable (ns)* field shown in Figure 12.

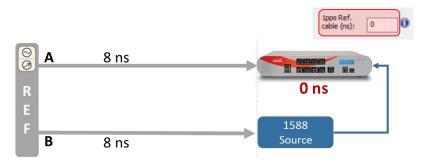
The examples below show the three scenarios that may be encountered, and the correct compensation value for each.

Timing	Control ToD 1588
Del	k Mode I step dock (Sync) 2 step dock (Sync+Follow Up) ay Timing Measurements Include CorrectionField in Delay Calculation schure 1588 Packet Rate 10 Packets/s
Abs	olute Time Lodsing Start capture at Top of Second of Ipps Reference Input (if present) DUT Ethernet cable calibration (ns): Upps Reference cable calibration (ns):
	······································
Compens	ation Field Figure 13

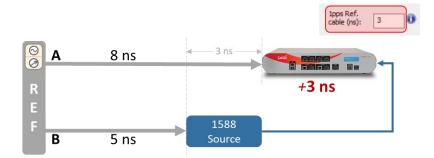
Test Configura	tion —	•
DUT Ethernet	0	0
1pps Ref. cable (ns):	0	0
1pps Meas. cable (ns):		os ref. elay

Figure 12

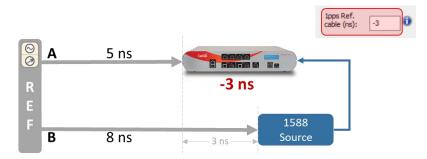
Example 1 – Identical cable lengths:



Example 2 – Paragon-X cable is longer:



Example 3 – Paragon X-cable is shorter:



6. 1pps cable termination

G.8271 Annex A indicates that there is a 10ns uncertainty associated with the rising edge of the 1pps pulse. It is important that the Paragon-X termination impedance is correctly matched to the source signal impedance, and that the interconnecting cable used has the correct impedance, or the rising edge of signal will degrade, leading to greater measurement uncertainty.

It is recommended for TTL signals that 50Ω coaxial cable is used for the cable run.

Later versions of Paragon-X termination for 1pps input may be configured as 'High Impedance' or 50Ω to match the signal requirements. Earlier versions support 50Ω termination only.

7. 1pps threshold levels

It is important to ensure the input signal integrity when using 1pps. G.8271 Annex A suggests the uncertainty of the rising edge of a 1pps signal may be up to 10ns. If the signal level is not correct, this uncertainty can significantly increase.

If there is concern regarding the signal integrity of a 1pps pulse, it should be checked using an oscilloscope, with careful attention paid to the rise time and amplitude of the signal. Measuring the amplitude allows a suitable threshold value to be configured in Paragon-X. By convention this threshold should be set at 50%; configuration of this on Paragon-X is as shown in Figure 14.

File Instrument Setup Capt	ture Impair Graph Data Tools Help	
* - * • *		
Start Up	SETTINGS Arrival Time Msa Type ToD Messaae	
	Ethemet 10GBE 10GPF	
Operating Mode	N/A Setup Interface	? ×
Setup Interface	Thu TEMU Ethernet References Measurement Ports ToD 1 Thu TEMU TEMU TEMU Measurement Input (Upper Front Aux Port)	
Master/Slave/GPS Emulation	STATUS Threshold: 1.6 V (Range: 0.5 V to 2.5 V)	
Measurements	Per 1 Termination: C High Impedance C 50 Ohm 0 El Wander Measurement Port	
Select Flow	Raf C ENC C Bantam	ld
Configure Capture	IPPS Ref	
Start Capture	FLOW FILTER Post 2 Tx	
Add Impairments/ Delay	Flow 1. SET Flow 2. xxx Flow 3. xxx	
Add Wander	Flow 4. sox Set	
Add Jitter		Close
Packet Generation		
Statistics/ Results		

Figure 14

The 1pps reference input can also be adjusted as shown in Figure 15.

File Instrument Setup Capt	ture Impair Graph Data Tools Help
*	
Start Up	SETTINGS Arrival Time Msa Tvoe ToD Messace
	Ethemet 1008E_100PT
Operating Mode	NAA Setup Interface
Setup Interface	Ethernet: References Measurement Ports ToO
Master/Slave/GPS Emulation	STATUS Fixt. BNC Fixt. Bantam Fixt. D-type C 10MHz C T1 ternary C 460/s Pot 1 C E1/2.0480Hz C E1 ternary
Measurements	Ink Link Ipps Reference Input Short MCE Marter
Select Flow	Ref C (BV)C C (GPS D-4)pe C Internal Using type Ref Wander Threshold: 1.6 V (Range: 0.5 V to 2.5 V) Master 1
Configure Capture	1998 Raf Jitter Termination: C High Impedance C 50 Ohm
Start Capture	Put2 Tx External Wander Generation 1pps Ref. threshold
Add Impairments/ Delay	Flow 1: SET Reference Output (Lower Front Aux Port) Flow 2: xxx 10 MHz and tops
Add Wander	Flow 4 - xxx Ipps width: 20000 μs (Range: 1 to 500,000 μs)
Add Jitter	Close
Packet Generation	
Statistics/ Results	

Figure 15

8. Connector type conversion

In some situations, the connector type on the source or terminating equipment are not of the same type and therefore an adaptor or conversion cable will be required to facilitate interoperability, these can be purchased or constructed. These should be well made and must not affect the voltage levels and/or pulse shape of the 1pps signal. In particular, it is vital the rising edge of the pulse is not affected as this is the edge used to register the top-of-second event. If in doubt, examine the pulse shape using an oscilloscope.

For example, if it is necessary to construct a 1pps conversion, between a BNC connector and a RJ45 connector, it is recommended that the majority of the length of the cable uses a coaxial 50Ω single-ended cable (as typically used with BNC connectors). The length of twisted pair Ethernet cable joining the coaxial cable to the RJ45 should be as short as possible to reduce additional skew on the rising edge of the 1pps pulse caused by impedance mismatch.

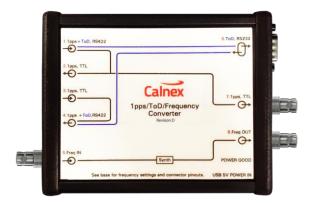
9. 1pps/ToD/frequency convertor

Calnex offers a convertor accessory (option 133) to ease interconnection issues.

The following table describes the device functionality. Additional reference frequency conversion ratios may be available, contact Calnex for more information.

A method to determine the delays is provided in the Calnex FAQ (keyword "Option 133") accessed through the support pages at <u>www.calnexsol.com</u>.

Size: 140 x 35 x 105mm Weight: 320g



Functions	Input	Output
Combined differential 1pps+ToD serial signal conversion to separate 1pps TTL and ToD RS- 232 signals	RJ-45 connector (see port 1 pinout above). Combined differential (RS-422) 1pps and ToD. Normally connected to subordinate clock output.	1pps TTL (single-ended) pulse on RJ-45 connector (port 2) and ToD RS-232 signal on DB9 connector (port 6). Normally connected to Paragon 1pps and GPS inputs. Use crossover (null modem cable) to connect ToD RS-232 cable from accessory to Paragon.
1pps TTL signal connector adapter	RJ45 connector (port 3), TTL high impedance	BNC female connector (port 7), TTL 50Ω
1pps TTL signal format converter	RJ45 connector (port 3), TTL high impedance	RJ-45 connector (port 4), RS-422
10MHz wander measurement vs. 10MHz reference on Paragon	10MHz on BNC female connector (port 5). Normally connected to subordinate clock output.	2MHz on BNC female connector (port 8), which tracks input 10MHz wander. Normally connected to Paragon 2MHz wander measurement input.
5/15MHz reference signal to 10MHz conversion. Switch selectable.	5/15MHz on BNC female connector (port 5). Normally connected to 5/15MHz reference source.	10MHz on BNC female connector (port 8), frequency locked to input. Normally connected to Paragon 10MHz reference input.



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