Engine Position Tracking VI User's Manual

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Introduction

The Drivven family of Engine Position Tracking (EPT) VIs track the angular position of a wide variety of crankshaft trigger patterns within the LabVIEW FPGA environment. Each VI provides a standardized interface to higher level CPU algorithms and also with other fuel and spark LabVIEW FPGA VIs which it supervises. The EPT VIs are designed to track engine position and supervise fuel and spark output VIs so that the CPU is required to respond to little or no engine synchronous events. Flags are provided for errors. Once initialized, the EPT VIs, combined with any number of fuel and/or spark VIs, are capable of operating fully autonomously.

Features:

- Angular crankshaft position tracking to approximately 0.1 crank angle degree resolution
- Supports N-M, N+1 and encoder style patterns
- Supports 2-stroke and 4-stroke engine configurations
- Built in crankshaft and camshaft pattern simulation for bench testing applications without a running engine
- Supervises any number of fuel and spark control VIs from Drivven
- Standardized interfaces to reduce high level CPU code modifications when changing engine configurations
- Provides outputs for speed, position, tooth count, tooth edge, sync and errors

Software

The Drivven Engine Position Tracking (EPT) VIs track angular position over 2-stroke or 4-stroke engine cycles of a wide variety of crankshaft and camshaft pattern types. The EPT LabVIEW FPGA VIs are configured by Drivven for a customer's specific pattern type, stroke and tooth count. Currently, Drivven supports the pattern types shown in table 1. Each pattern type may have a range of acceptable tooth count configurations or a fixed tooth count due to the nature of the pattern. Pattern types are supported separately by EPT VIs so that each VI can be optimized for its particular pattern to consume as few FPGA resources as possible.

VERY IMPORTANT NOTES:

The FPGA VIs require:

- LabVIEW 8.0 or later
- LabVIEW RT Module 8.0. or later
- LabVIEW FPGA Module 8.0 or later
- NI-RIO 2.0 or later

The FPGA VIs must be placed within a Single Cycle Loop (SCL) of a LabVIEW FPGA block diagram. The SCL must execute at the default clock rate of 40 MHz.

The FPGA VIs requires a pre-synthesized netlist file having a matching name and an extension of .ngc. The netlist file must be located in the same directory as the matching VI.

When interfacing Drivven CompactRIO module VIs with the EPT VIs, the FPGA VIs require the installation of a special CompactRIO module support package called cRIO-generic. Please follow the steps below to install the cRIO-generic package:

1. Confirm that LabVIEW is closed.
2. Add the line **`cRIO_FavoriteBrand=generic`** to the LabVIEW INI file. The LabVIEW INI file is typically found at C:\Program Files\National Instruments\LabVIEW 8.0\LabVIEW.ini.
3. Upon restarting LabVIEW, the cRIO-generic module will appear in the list of available modules within the LabVIEW FPGA “New C Series Module” configuration dialog. All Drivven CompactRIO modules require adding an associated cRIO-generic module to your LabVIEW Project. Within the Project Explorer, A cRIO-generic module can be added to a PXI FPGA expansion chassis or a CompactRIO chassis. This is best understood by observing an example project provided with your module kit.

WARNING!

When writing values to an FPGA cluster from the RT level, every parameter within the cluster must be explicitly written. If any parameter is not explicitly written, then the default value for that particular data type will be used. This could cause unexpected behavior.

Table 1. Supported EPT Patterns

EPT VI Directory Name Format	Pattern Name	Pattern Description
ept_nm_revx_XXX-X_X_XXXX	nm (N-M)	N-M patterns have N evenly spaced teeth and M missing adjacent teeth (gap) on the crankshaft trigger wheel. M is limited to 1 or 2 missing teeth. N is stated in terms of evenly spaced teeth, as if there were no missing teeth. For example, a 60-2 pattern would consist of 58 physical teeth followed by two missing teeth. EPT N-M VIs can be configured to track 360 or 720 degrees depending upon an optional camshaft input. When tracking 360 degrees for 2-stroke engines, the camshaft input is ignored. This is designated by configuring the VI with STROKE = 2. When tracking 720 degrees for 4-stroke engines, the camshaft input signal must be TRUE at every other crank tooth gap. This is designated by configuring the VI with STROKE = 4.

Table 1. Supported EPT Patterns (continued)

ept_p1a_revx_XXX_X_XXXX ept_p1m_revx_XXX_X_XXXX ept_p1r_revx_XXX_X_XXXX	p1 (N+1)	N+1 patterns have N evenly spaced teeth and a single additional tooth (Plus1), placed between two evenly spaced teeth, on the crankshaft trigger wheel. The Plus1 tooth can be located at one of three different positions between two evenly spaced teeth – advanced, midpoint, or retarded. N is stated in terms of evenly spaced teeth, as if there were no additional teeth. For example, a 6+1 pattern would consist of 6 physical evenly spaced teeth and an additional physical tooth placed between two evenly spaced teeth. EPT N+1 VIs can be configured to track 360 or 720 degrees depending upon an optional camshaft input. When tracking 360 degrees for 2-stroke engines, the camshaft input is ignored. This is designated by configuring the VI with STROKE = 2. When tracking 720 degrees for 4-stroke engines, the camshaft input signal must be TRUE at every other Plus1 tooth. This is designated by configuring the VI with STROKE = 4.
ept_enc_revx_XXX_X_XXXX	enc (Encoder)	Encoder patterns have N evenly spaced teeth on the crankshaft with a single reference tooth on the camshaft. The rising or falling edge of the reference tooth must occur between the same two crankshaft teeth each cycle. The EPT ENC VI can be configured to track 360 or 720 degrees depending upon the location of the reference tooth. When tracking 360 degrees, the reference tooth is located on the crankshaft, yet is wired to the CamSig input of the EPT VI. When tracking 720 degrees, the reference tooth is located on the camshaft. Encoder style patterns are a very common form of engine position tracking in both production and research engine control systems.

Figure 1 shows the icon which represents all EPT VIs, having identical clustered terminals.

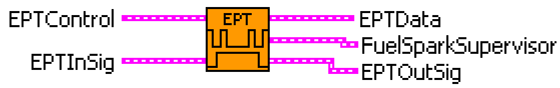


Figure 1. EPT VI icon with leads.

The EPT VIs are required for supervising all Drivven fuel and spark VIs, which are included with the fuel and spark cRIO module kits. The EPT VI provides the necessary FuelSparkSupervisor output cluster to be wired to the similarly named input clusters of the fuel and spark VIs. Also, the EPT VIs must be specifically configured by Drivven according to the engine's specific crank/cam pattern configuration. Therefore, there must be a configuration match between EPT VIs and the fuel and spark VIs for proper operation. In order to track VI configuration, the name of the EPT VI directories provided to the customer have a five-component suffix according to Figure 2. The EPT VI directory will also contain similarly named directories for fuel or spark control VIs, as shown in Figure 3.

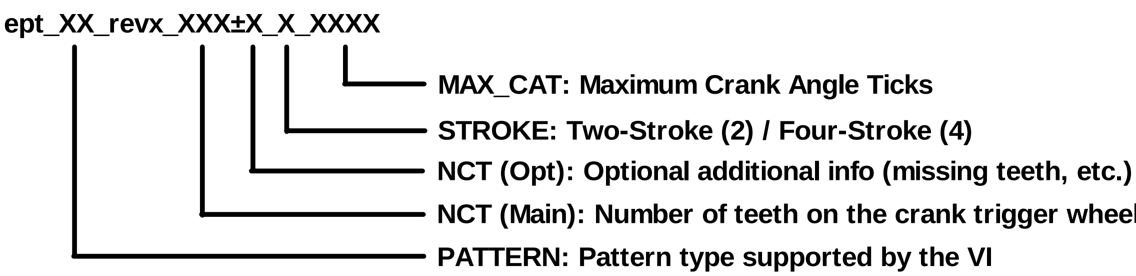


Figure 2. EPT VI directory name format.

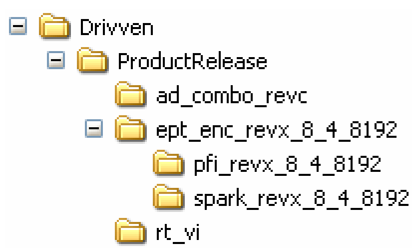


Figure 3. EPT VI directory name example.

According to the example shown in Figure 3, the EPT VI directory will contain a copy of the standard EPT VI for encoder patterns named ept_enc_revx.vi. It will also contain a synthesized FPGA netlist file named ept_enc_revx.ngc. The netlist file will be synthesized for a four-stroke encoder pattern having 8 crank teeth and a maximum Crank Angle Ticks of 8192. Any fuel or spark modules that are obtained for the same pattern configuration will have directories directly under the ept directory and have a similar name format.

When ordering an EPT VI from Drivven, PATTERN, NCT and STROKE must be provided to generate the VI netlist. After the purchase of a single pattern type, additional tooth count configurations within that same pattern type can be configured for the customer for a small fee. Drivven is working to support additional pattern types with a compatible interface. If a particular pattern is not supported, please contact Drivven with the desired pattern specifications. Drivven can provide custom pattern position tracking.

EPT VI Commonality

All EPT VIs have a common internal core that tracks angular position. The supporting internal software around the core interprets the incoming crank and cam position pulses according to an expected pattern. Each EPT VI has a crankshaft and camshaft input. These signals should be wired from the VR or Hall outputs from the ad_combo.vi or vr_hall.vi provided with Drivven's AD Combo or VR/Hall cRIO Module Kits. The pattern input signals are named according to the most common engine applications, such that there is a crankshaft trigger wheel and an optional 4-stroke camshaft trigger wheel. However, it is also possible for some VI pattern types to operate with a single trigger wheel pattern mounted to a camshaft. This would require routing the camshaft trigger wheel sensor signal into the crankshaft input of the EPT VI. The EPT VI, however must be configured as a two-stroke application. Please contact Drivven for support for these configurations.

EPT Pattern Simulation

All EPT VIs contain a built in pattern simulation tool specific to the pattern for which the EPT VI was configured. Pattern simulation is turned on simply by setting SimEnable to TRUE and setting the SimPeriod to a value equivalent to 60 RPM or greater. These controls are found within the EPTControl cluster. The simulated crank and cam signals are output on the SimCrankSig and SimCamSig indicators within the EPTOutSig cluster. When simulation is turned on, the CrankSig and CamSig inputs to the EPT VI are internally disconnected and replaced by the simulated counterparts. The simulation feature allows the designer to bench test the engine control system functionality at any stage of the development without the need for external simulation hardware. The simulated crank and cam signals can be monitored on an oscilloscope while also monitoring the fuel and/or spark actuators to verify the control strategy.

Starting Position Tracking (Sync)

In order for position tracking, or sync, to start, a few conditions must be met. First, the CPU must enable sync by setting SyncEnable to TRUE. Then the crankshaft must achieve a speed of at least 60 RPM. When 60 RPM or greater is maintained, the Stalled output within the EPTData cluster will be set to FALSE and the EPT VI begins counting a minimum of 8 or NCT/2 crank teeth, whichever is greater. This minimum crank tooth count is called CRANK_COUNT_START. After CRANK_COUNT_START is met, the EPT VI begins looking for the first occurrence of a unique feature of the crankshaft and camshaft pattern which identifies an absolute position. For example, if an N-M pattern is being used, the VI searches for the occurrence of the M-tooth gap. This is the moment of achieving sync. When sync is achieved, the SyncStopped output within the EPTData cluster is set to FALSE. Each EPT VI will have different rules for achieving and maintaining sync. This information is contained in the documentation below, specific for each pattern type.

Period, PeriodAccum, CrankCount and CurrentPosition

During sync, the EPT provides the latest period between trigger teeth at the Period output within the EPTData cluster in terms of 40 MHz clock ticks. Period is reported as though there were no missing or extra teeth. Therefore the CPU may use this value for calculating the latest instantaneous engine speed. Another output value named PeriodAccum within the EPTData cluster contains an accumulation of Period values over NCT. This value is updated upon each rotation of the crankshaft. PeriodAccum may be used to easily calculate an average crankshaft speed over a complete rotation. Crankshaft speed may be calculated in RPM according to the following:

EngineSpeedInst(RPM) = (60 * 4E7) / (Period * NCT) = 2.4E8 / (Period * NCT)

EngineSpeedAve(RPM) = (60 * 4E7) / PeriodAccum = 2.4E8 / PeriodAccum

Drivven provides utility VIs which can be implemented at the LabVIEW RT level for performing these calculations. The VI named ticks2speed.vi can be used to convert Period to RPM. For simulation purposes, the VI named speed2ticks.vi can be used to convert RPM setpoint to SimPeriod. The icons for these VIs are shown in Figure 4.

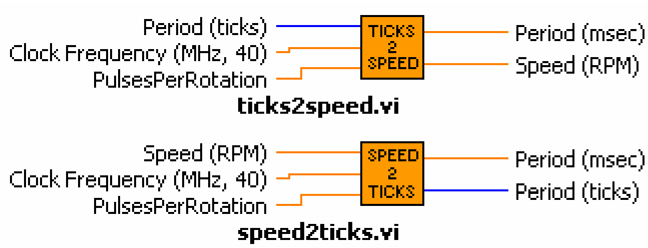


Figure 4. Period / Speed conversion VIs.

During sync, the EPT provides the latest crank tooth count at the CrankCount output within the EPTData cluster, referenced to tooth 0. Tooth 0 is determined according to the pattern that is being tracked and is discussed below within the pattern specific documentation. CrankCount is provided in terms of a complete engine cycle and is reported as if there were no missing or extra teeth in the pattern. For example, if PATTERN = N-M, NCT = 60 and STROKE = 4, then CrankCount will range from 0 to 119.

During sync, the EPT provides the latest crankshaft position at the CurrentPosition output within the EPTData cluster in terms of absolute Crank Angle Ticks (CAT) over a complete engine cycle, referenced to position 0. Position 0 is determined according to the pattern that is being tracked and is discussed below within the pattern specific documentation. Drivven configures each EPT VI for a target positional resolution of 0.1 Crank Angle Degrees (CAD). The actual resolution will vary from the target resolution, but no more than +/-0.05 CAD. The resolution is configured with power-of-two math. For example, if PATTERN = NM, NCT = 60 and STROKE = 4, then the EPT VI name would be derived as ept_nm_revx_60-2_4_7680. The last component of the VI name is MAX_CAT = 7680. This is the total number of angular positional ticks that are tracked by the EPT over a complete engine cycle. Therefore CurrentPosition will track from 0 to 7679 and roll over to 0 at the occurrence of tooth 0. This provides an angular resolution of 0.093 CAD/CAT. The angular position in CAD can be calculated according to the following:

CurrentPosition(CAD) = [CurrentPosition(CAT) * (STROKE / 2) * 360] / MAX_CAT

Drivven provides a utility VI which can be implemented at the LabVIEW RT level for performing this calculation. The VI named CAT2CAD.vi can be used to convert CAT to CAD. This VI icon is shown in Figure 5.

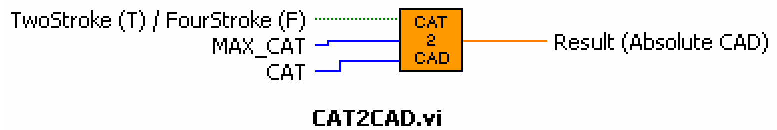


Figure 5. CAT / CAD conversion VI.

Loss of Sync

The EPT VI will lose sync when missing or extra crank or cam pulses are encountered where unexpected. A loss of sync will be signaled by the appropriate pattern-specific error flag within the EPTData cluster. An obvious possible reason for such errors would be that the crank or cam trigger wheel pattern does not match the configuration of the EPT VI. If this is the case, the EPT will either not sync at all or will lose sync almost immediately after initial sync. Assuming that the trigger pattern is correct, there are a few other common sources of losing sync. The two most common sources are electrical noise and mechanical trigger wheel imperfections.

Electrical noise can be picked up and manifested in a wide variety of ways. The Drivven AD_Combo and VR/Hall Modules' adaptive VR sensor inputs and hall-effect sensor inputs perform very well at rejecting electrical noise. The documentation for the AD_Combo Module Kit should be consulted for more information about VR and hall-effect sensor input channel configuration. However, there are a few guidelines that should be followed for ensuring appropriate immunization to electrical noise. It is unlikely that noise will be introduced on the crank or cam signals between the cRIO module and the main RIO FPGA. It is most likely that electrical noise will be picked up between the sensor and the external connection to the module. If possible, the wiring for VR sensors should be a twisted shielded pair and as short as possible. Hall-effect sensor wiring should also preferably be shielded and as short as possible. There should be few (or no) electrical connections between the sensor and the module. The output of Drivven's VR sensor circuit is a 50 microsecond one-shot signal to the RIO FPGA upon receiving a VR pulse. If external noise is significant enough to be accepted as an actual VR pulse, then a similar one-shot output will be generated. Therefore, filtering logic within the RIO FPGA will not offer any benefits. Efforts should be focused on external wiring. The output of Drivven's hall-effect sensor circuit follows the input with a small analog filter delay. If noise glitches appear on this signal at the RIO FPGA, then a digital filter may offer some benefit. Drivven recommends using the integrating digital filter offered with the AD_Combo and VR/Hall Module Kits, only after external wiring efforts have been exhausted.

Mechanical trigger wheel imperfections, if sensed by a VR sensor, will usually manifest themselves as significant VR pulses at higher engine speeds. Trigger wheels are machined in two varieties: positive teeth or negative teeth (slots). Sometimes positive teeth will have distinct edges left behind by the machining process at the rising or falling edge of the mechanical tooth. At low speeds it may be difficult to see a resulting VR pulses on an oscilloscope, and the EPT will sync just fine. However, at higher speeds the generated pulse from the imperfection may become significant enough to be accepted by the VR input circuit. Drivven's VR circuits are adaptive and will reject a pulse that is approximately 50% amplitude of the pulse before it, if the imperfection is immediately following a real tooth. As the imperfection becomes farther away from a real tooth, the triggering threshold becomes lower. Negative trigger teeth, or slotted wheels can also have imperfections along the flat surfaces where no slots are present. Since the sensor is mounted very close to these flat areas, they will be sensitive to imperfections in the surface. Therefore it may be required to increase the sensor gap or remove the offending imperfections if they cause false outputs to the RIO FPGA.

Achieving reliable, clean crank and cam signals can sometimes be a trial and error process. It is Drivven's experience that this setup process usually does not work perfectly with the first attempt at running the engine over the entire speed and load range. Even though sync may occur reliable at low engine speeds does not mean that there will not be signal issues at high speeds or loads due to trigger wheel imperfections, ignition system noise, or camshaft position lash with respect to the crankshaft. The system designer should take care to check that external signal shielding and routing are optimal and that there is plenty of margin for cam belt or chain stretch. It is always useful to have access to a good triggering multi-channel mixed signal oscilloscope. Drivven strives to make the engine control prototyping process as rapid as possible with modular products that are quickly configured. However, patience and perseverance are still required as always.

With that said, there are some tricks the designer can employ with the use of an oscilloscope to locate the source of sync problems. After all, finding the source of a problem is most of the battle. If the EPT error flags are routed out to external digital outputs via unused cRIO slot pins, they can be used as triggers to capture crank and cam signal problems. This is where a multi-channel mixed signal oscilloscope is so useful. For example, the designer could route the CrankSig, CamSig and ErrorFlag signals out to unused cRIO slot pins. These signals could be monitored on digital or analog scope channels. The external VR and/or hall-effect signals could also be monitored on the scope's analog channels. By triggering on the rising edge of one of the error flags, it would be possible to see the occurrence of signal imperfections on the external signals. It would also be possible to see the correlation between the external signals and the signals presented to the CrankSig and CamSig inputs. This information can be used to determine the proper problem-solving action to take.

The EPT will also lose sync if the crankshaft speed falls below 60 RPM. When sync is lost, CrankCount and CurrentPosition will be set to 0 and SyncStopped will be set to TRUE. When crank speed falls below 60 RPM, Period and PeriodAccum will be set to 0 and Stalled will be set to TRUE. When calculating engine speed from Period, be sure to check for this zero condition, otherwise a divide-by-zero condition will be encountered. The ticks2speed.vi accounts for this.

Position Tracking

Between each crank tooth, CurrentPosition is incremented smoothly at a rate proportional to the previous crank tooth period. In the presence of crankshaft acceleration or deceleration, sync is still properly maintained. If a new crank tooth is received before CurrentPosition has incremented to the correct position, then CurrentPosition is incremented at a faster rate until proper synchronization is achieved. CurrentPosition is then further incremented at a rate proportional to the previous crank tooth period. If CurrentPosition reaches the correct position expected for the next tooth before the tooth is received, then CurrentPosition holds its value until the next crank tooth. This mechanism, along with the aid of other unique pattern specific features make the EPT VIs a very robust position tracking algorithm.

Block Diagram Design
The EPT VIs must be placed within a Single Cycle Loop (SCL) of a LabVIEW FPGA block diagram. The SCL must execute at the default clock rate of 40 MHz.

Each EPT VI requires a pre-synthesized netlist file having a matching name and an extension of .ngc. The netlist file must be located in the same directory as the VI.

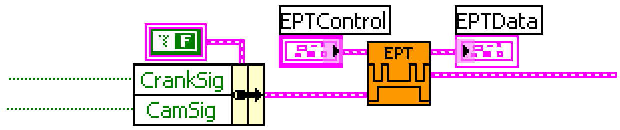


Figure 6. Example block diagram implementation of EPT VIs.

EPTInSig (Cluster)

CrankSig (boolean): The digital input signal representing the crankshaft trigger wheel pulse train. This input should be wired directly from a VR or Hall output of the AD Combo or VR/Hall Module Kit VI. The EPT VI responds to the rising edge of CrankSig.

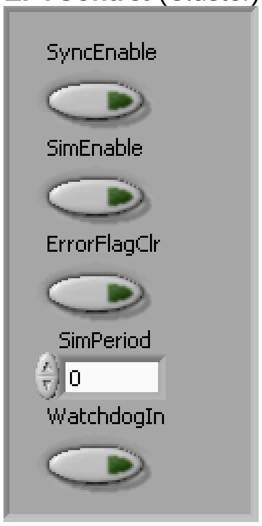
CamSig (boolean): The digital input signal representing the camshaft trigger wheel pulse train. This input should be wired directly from a VR or Hall output of the AD Combo or VR/Hall Module Kit VI. For some pattern types, the EPT VI responds to the rising edge of CrankSig. For other pattern types, the EPT VI tests the level of CamSig.

EPTOutSig (Cluster)

SimCrankSig (boolean): Digital output signal generated by the built-in pattern simulation tool to simulate the crankshaft pattern for which the EPT VI is configured.

SimCamSig (boolean): Digital output signal generated by the built-in pattern simulation tool to simulate the camshaft pattern for which the EPT VI is configured.

EPTControl (Cluster)



SyncEnable (boolean): When TRUE, sync is enabled and position tracking will take place if a valid crank and cam signal pattern is presented to the EPT VI at an engine speed greater than 60 RPM.

SimEnable (boolean): When TRUE, CrankSig and CamSig inputs within the EPTInSig cluster are internally disconnected from the position tracking core and simulated signals are connected in their place.

ErrorFlagClr (boolean): The names and number of error flags will vary depending on EPT pattern type. When TRUE, the corresponding error flag output within the EPTData cluster will be cleared.

SimPeriod (uint32): The simulated period between evenly spaced crank teeth in terms of 40 MHz clock ticks. SimPeriod is only effective when it is set to a non-zero value while SimEnable is TRUE. The EPT will not sync to the simulator unless the effective engine speed is greater than 60 RPM. Engine speed in RPM can be converted to SimPeriod in 40 MHz clock ticks according to the following equation:

SimPeriod(clock ticks) = (60 * 4E7) / (EngineSpeed(RPM) * NCT)

= 2.4E8 / (EngineSpeed(RPM) * NCT)

WatchdogIn (boolean): The WatchdogIn boolean signal must be toggled at a rate greater than 10 Hz. The purpose of the watchdog is to shutdown engine position tracking (as well as any engine synchronous outputs) in the case of a loss of LabVIEW RT communication with the FPGA. For example, the LabVIEW RT application may fail due to coding errors without properly closing the FPGA application. It would not be desirable for the EPT to continue tracking engine position and supervising engine synchronous outputs according to the last command received from the LabVIEW RT application. Figure 7 shows an example of toggling the WatchdogIn signal with a simple while loop structure within LabVIEW RT. The toggled signal is wired to the WatchdogIn element of a Cluster Bundle By Name function.

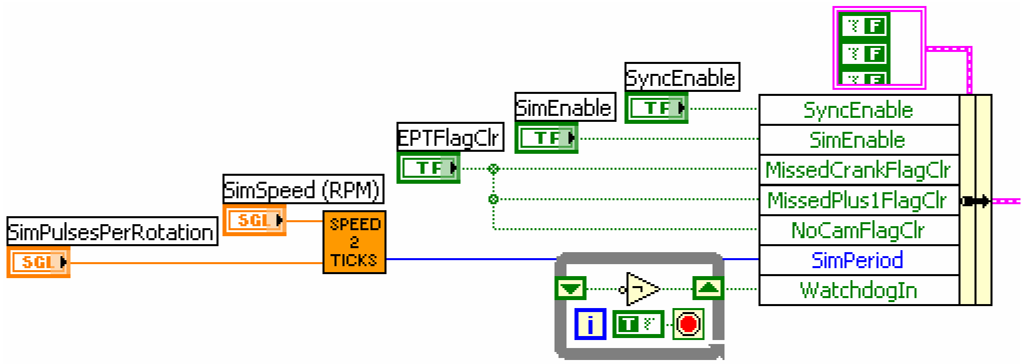
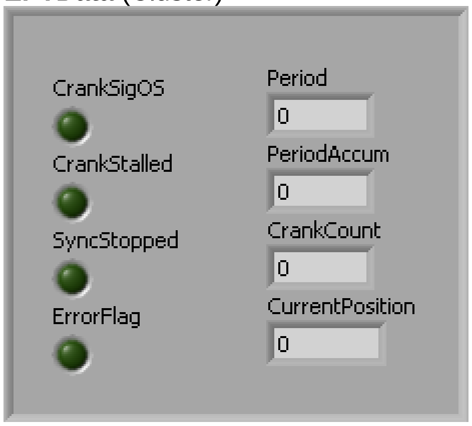


Figure 7. Example of toggling the WatchdogIn.

EPTData (Cluster)



CrankSigOS (boolean): A 40 MHz one-clock one-shot generated at the rising edge of each received or simulated CrankSig input. This signal can be used in conjunction with CrankCount for any purpose within LabVIEW FPGA logic to perform engine synchronous tasks.

CrankStalled (boolean): Set to TRUE when the engine speed is below 60 RPM.

SyncStopped (boolean): Set to TRUE while position tracking is not taking place. In other words, no sync.

ErrorFlag (boolean): The names and number of error flags will vary depending on EPT pattern type. When TRUE, the EPT VI has detected an error while tracking crankshaft position. The resulting actions are pattern-specific. Error flags are cleared by setting the corresponding flag within the EPTControl cluster to TRUE.

Period (uint32): The period between the last two crank trigger teeth, as if there were no missing or extra teeth, in terms of 40 MHz clock ticks. Period will be set to 0 while Stalled is TRUE. Period in clock ticks can be converted to instantaneous engine speed in RPM according to the following equation:

$$\text{EngineSpeedInst(RPM)} = (60 * 4E7) / (\text{Period} * \text{NCT})$$

$$= 2.4E8 / (\text{Period} * \text{NCT})$$

PeriodAccum (uint32): The accumulated period over a complete crankshaft rotation in terms of 40 MHz clock ticks. PeriodAccum will be set to 0 while Stalled is TRUE. PeriodAccum in clock ticks can be converted to average engine speed in RPM according to the following equation:

$$\text{EngineSpeedAve(RPM)} = 60 * 4E7) / \text{PeriodAccum}$$

$$= 2.4E8 / \text{PeriodAccum}$$

CrankCount (uint16): The latest tooth count referenced to crank tooth 0. Tooth 0 is determined according to the pattern that is being tracked and is discussed within the pattern specific documentation. CrankCount is provided in terms of a complete engine cycle and is reported as if there were no missing or extra teeth in the pattern. For example, if PATTERN = N-M, NCT = 60 and STROKE = 4, then CrankCount will range from 0 to 119.

CurrentPosition (uint16): The current angular position of the crankshaft in terms of absolute Crank Angle Ticks (CAT) over a complete engine cycle, referenced to position 0. Position 0 is determined according to the pattern that is being tracked and is discussed within the pattern specific documentation. Drivven configures each EPT VI for a target positional resolution of 0.1 CAD. The actual resolution will vary from the target resolution, but no more than +/-0.05 CAD. The resolution is configured with power-of-two math. For example, if PATTERN = NM, NCT (N) = 60, M = 2 and STROKE = 4, then the EPT VI name would be derived as ept_nm_revx_60-2_4_7680. The last component of the VI name is MAX_CAT = 7680. This is the total number of angular ticks that are tracked by the EPT over a complete engine cycle. Therefore CurrentPosition will track from 0 to 7679 and roll over to 0 at the occurrence of tooth 0. The angular position in CAD can be calculated according to the following:

CurrentPosition(CAD) = [CurrentPosition(CAT) * (STROKE / 2) * 360] / MAX_CAT

FuelSparkSupervisor (Cluster)
This cluster output must be wired directly to the FuelSparkSupervisor cluster inputs of Drivven fuel and/or spark VIs.

Pattern Specific Information

N-M Patterns

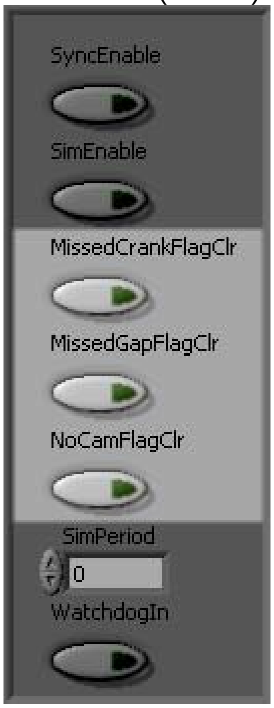
Pattern Description:
N-M patterns have N evenly spaced teeth and M missing adjacent teeth (gap) on the crankshaft trigger wheel. M is limited to 1 or 2 missing teeth. N is stated in terms of evenly spaced teeth, as if there were no missing teeth. For example, a 60-2 pattern would consist of 58 physical teeth followed by two missing teeth. EPT N-M VIs can be configured to track 360 or 720 degrees depending upon an optional camshaft input. When tracking 360 degrees for 2-stroke engines, the camshaft input is ignored. This is designated by configuring the VI with STROKE = 2. When tracking 720 degrees for 4-stroke engines, the camshaft input signal must be TRUE at every other crank tooth gap. This is designated by configuring the VI with STROKE = 4.

2-Stroke Applications (STROKE = 2):
Position 0 and tooth 0 coincide with the first tooth following each crank tooth gap. The CamSig input is ignored. CrankCount will increment from 0 to NCT - 1. During crank tooth gaps, CrankCount will continue to increment at the location of each missing tooth. For example, if STROKE = 2, NCT (N) = 60 and M = 2, then CrankCount would increment from 0 to 59, such that teeth 58 and 59 would correspond to the two missing teeth and tooth 0 would correspond to the tooth following missing tooth 59.

4-Stroke Applications (STROKE = 4):
Position 0 and tooth 0 coincides with the first tooth following the crank tooth gap while the CamSig input is TRUE. The CamSig is actually only used for achieving initial sync. Once sync is achieved, it is maintained according to the location of each gap. However, CamSig is still monitored to make sure that its value is as expected during each gap. If CamSig is not at the expected level during each gap, then the NoCamFlag will be set to TRUE. The CPU is then able to make an appropriate decision. CrankCount will increment from 0 to 2*NCT - 1. During crank tooth gaps, CrankCount will continue to increment at the location of each missing tooth. For example, if STROKE = 4, NCT (N) = 60 and M = 2, then CrankCount would increment from 0 to 119, such that teeth 58 and 59 would correspond to the two missing teeth while CamSig is FALSE. Teeth 118 and 119 would correspond to the two missing teeth while CamSig is TRUE. Tooth 0 would correspond to the tooth following missing tooth 119.

The EPT N-M VI can achieve initial sync upon the first detected gap, whether CamSig is TRUE or FALSE. If CamSig is TRUE, sync will begin at position 0. If CamSig is FALSE, sync will begin at the mid-cycle position MAX_CAT / 2.

EPTControl (Cluster)

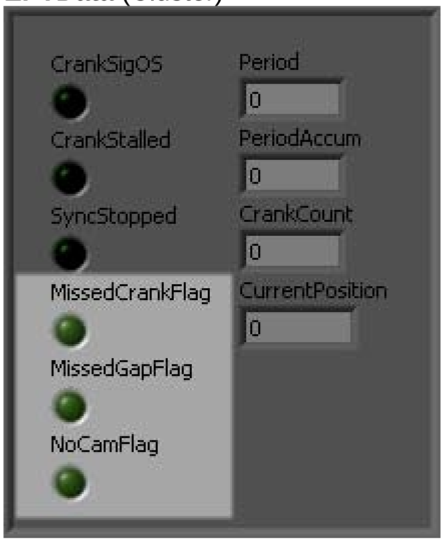


MissedCrankFlagClr (boolean): When TRUE, the MissedCrankFlag within the EPTData cluster will be cleared.

MissedGapFlagClr (boolean): When TRUE, the MissedGapFlag within the EPTData cluster will be cleared.

NoCamFlagClr (boolean): When TRUE, the NoCamFlag within the EPTData cluster will be cleared.

EPTData (Cluster)



MissedCrankFlag (boolean): Set to TRUE upon the detection of a crank tooth gap while the CrankCount value has not yet reached the expected value. In other words, a gap has been detected sooner than expected. This condition causes a loss of sync. Re-sync is not allowed until the flag is cleared by setting MissedCrankFlagClr to TRUE.

MissedGapFlag (boolean): Set to TRUE upon CrankCount being incremented past the expected value for the location of a gap before the gap is detected. In other words, physical teeth are received at the location where a gap is expected. This condition causes a loss of sync. Re-sync is not allowed until the flag is cleared by setting MissedGapFlagClr to TRUE.

NoCamFlag (boolean): Set to TRUE upon detecting 2 consecutive gaps without detecting a TRUE CamSig (STROKE = 4). CamSig is only sampled at gap detection. This condition does not cause a loss of sync. NoCamFlag is cleared by setting NoCamFlagClr to TRUE.

N+1 Patterns

Pattern Description:
N+1 patterns have N evenly spaced teeth and a single additional tooth (Plus1), placed between two evenly spaced teeth, on the crankshaft trigger wheel. There are three different sub-configurations within this pattern type. An advanced Plus1 tooth must be positioned such that it is advanced from the midpoint between two evenly spaced teeth. The amount of advance must be at least ¼ of the normal tooth spacing. A midpoint Plus1 tooth must be located at the midpoint between two evenly spaced teeth. A retarded Plus1 tooth must be positioned such that it is retarded from the midpoint between to evenly spaced teeth. The amount of retard must be at least ¼ of the normal tooth spacing. N is stated in terms of evenly spaced teeth, as if there were no additional teeth. For example, a 6+1 pattern would consist of 6 physical evenly spaced teeth and an additional physical tooth placed between two evenly spaced teeth. EPT N+1 VIs can be configured to track 360 or 720 degrees depending upon an optional camshaft input. When tracking 360 degrees for 2-stroke engines, the camshaft input is ignored. This is designated by configuring the VI with STROKE = 2. When tracking 720 degrees for 4-stroke engines, the camshaft input signal must be TRUE at every other Plus1 tooth. This is designated by configuring the VI with STROKE = 4.

2-Stroke Applications (STROKE = 2):
For advanced and midpoint Plus1 tooth configurations, position 0 and tooth 0 coincide with the first tooth following the Plus1 tooth. For retarded Plus1 tooth configurations, position 0 and tooth 0 coincide with the second tooth following the Plus1 tooth. The CamSig input is ignored. CrankCount will increment from 0 to NCT - 1. CrankCount will not be incremented at the location of the Plus1 tooth. For example, if the Plus1 tooth is advanced, STROKE = 2 and NCT = 6, then CrankCount would increment from 0 to 5, such that tooth 5 would correspond to the tooth immediately before the Plus1 tooth and tooth 0 would correspond to the tooth immediately following the Plus1 tooth.

4-Stroke Applications (STROKE = 4):
For advanced and midpoint Plus1 tooth configurations, position 0 and tooth 0 coincides with the first tooth following the Plus1 tooth while the CamSig input is TRUE. For retarded Plus1 tooth configurations, position 0 and tooth 0 coincide with the second tooth following the Plus1 tooth while the CamSig input is TRUE. The CamSig is actually only used for achieving initial sync. Once sync is achieved, it is maintained according to the location of each Plus1 tooth. However, CamSig is still monitored to make sure that its value is as expected during each Plus1 tooth. If CamSig is not at the expected level during each Plus1 tooth, then the NoCamFlag will be set to TRUE. The CPU is then able to make an appropriate decision. CrankCount will increment from 0 to 2*NCT - 1. CrankCount will not increment at the Plus1 tooth. For example, if the Plus1 tooth is advanced, STROKE = 4 and NCT = 6, then CrankCount would increment from 0 to 11, such that tooth 5 and tooth 11 would correspond to the tooth immediately before the Plus1 tooth while CamSig is FALSE and CamSig is TRUE, respectively. Tooth 6 and tooth 0 would correspond to the tooth immediately following the Plus1 tooth while CamSig is FALSE and CamSig is TRUE, respectively.

Tooth numbering for the three different Plus1 tooth location configurations is shown in figures 8, 9 and 10 below.

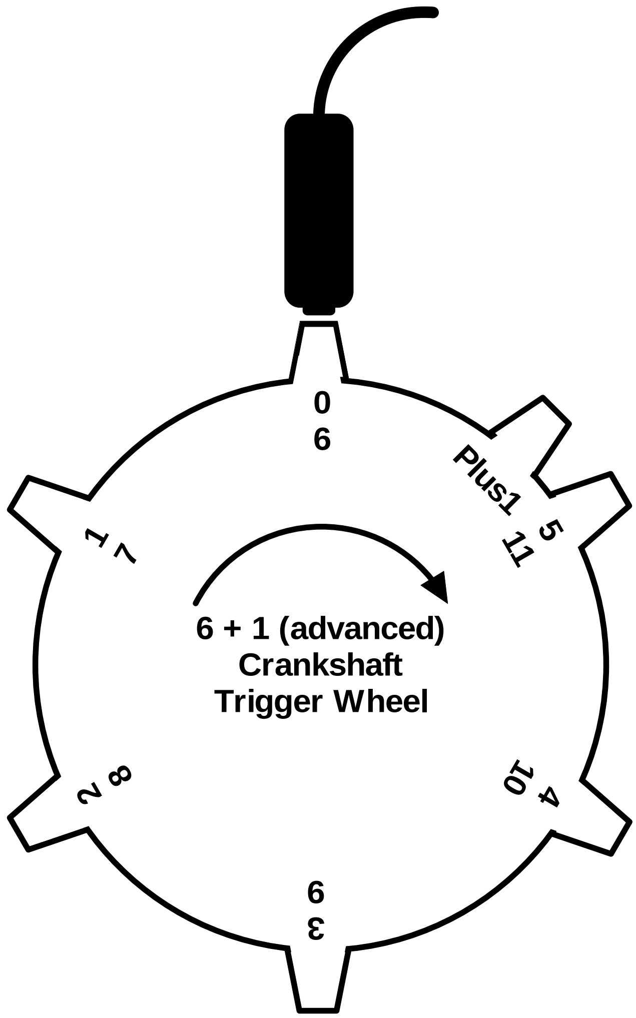


Figure 8. 6+1 (advanced) crankshaft trigger wheel tooth numbering

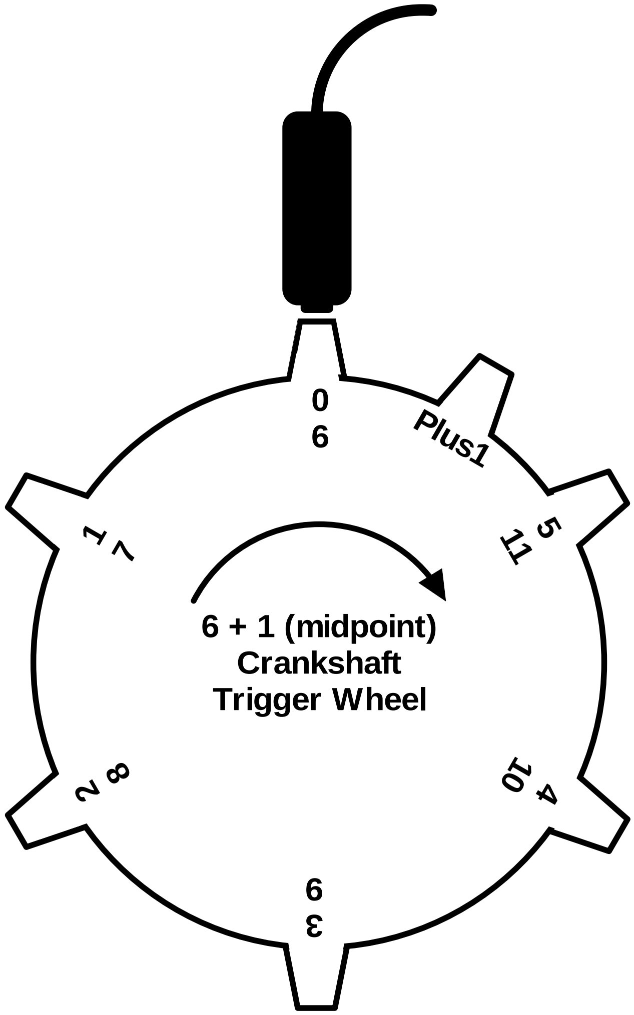


Figure 9. 6+1 (midpoint) crankshaft trigger wheel tooth numbering

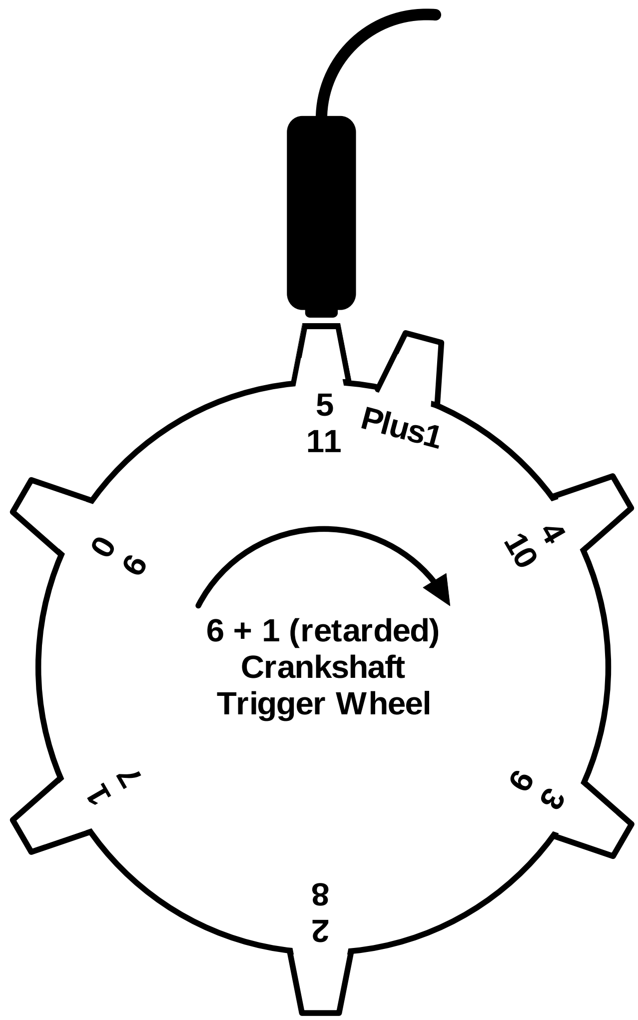
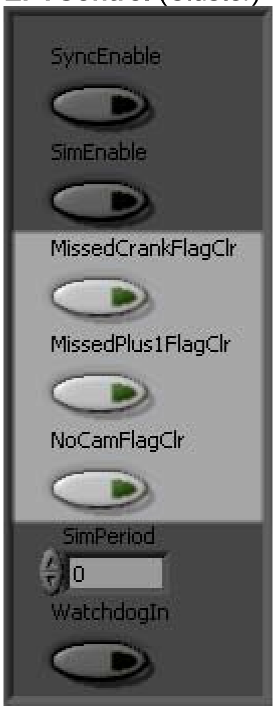


Figure 10. 6+1 (retarded) crankshaft trigger wheel tooth numbering

The EPT N+1 VI can achieve initial sync upon the first detected Plus1 tooth, whether CamSig is TRUE or FALSE. If CamSig is TRUE, sync will begin at position 0. If CamSig is FALSE, sync will begin at the mid-cycle position MAX_CAT / 2.

EPTControl (Cluster)

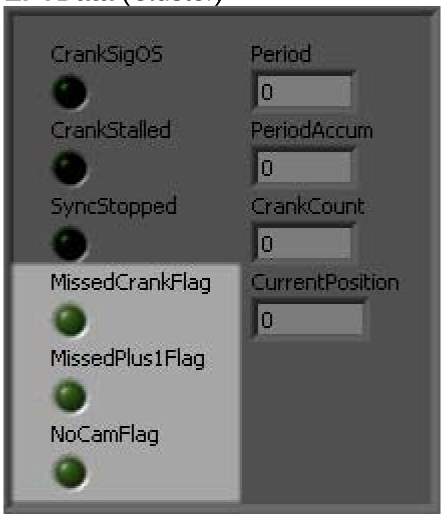


MissedCrankFlagClr (boolean): When TRUE, the MissedCrankFlag within the EPTData cluster will be cleared.

MissedPlus1FlagClr (boolean): When TRUE, the MissedPlus1Flag within the EPTData cluster will be cleared.

NoCamFlagClr (boolean): When TRUE, the NoCamFlag within the EPTData cluster will be cleared.

EPTData (Cluster)



MissedCrankFlag (boolean): Set to TRUE upon the detection of a Plus1 tooth while the CrankCount value has not yet reached the expected value. In other words, a Plus1 tooth has been detected sooner than expected. This condition causes a loss of sync. Re-sync is not allowed until the flag is cleared by setting MissedCrankFlagClr to TRUE.

MissedPlus1Flag (boolean): Set to TRUE upon CrankCount being incremented past the expected value for the location of a Plus1 tooth before the Plus1 tooth is detected. In other words, evenly spaced teeth are received at the location where a Plus1 tooth is expected. This condition causes a loss of sync. Re-sync is not allowed until the flag is cleared by setting MissedPlus1FlagClr to TRUE.

NoCamFlag (boolean): Set to TRUE upon detecting 2 consecutive Plus1 teeth without detecting a TRUE CamSig (STROKE = 4). CamSig is only sampled at Plus1 tooth detection. This condition does not cause a loss of sync. NoCamFlag is cleared by setting NoCamFlagClr to TRUE.

Encoder Patterns

Pattern Description:
Encoder patterns have N evenly spaced teeth on the crankshaft with a single reference tooth on the camshaft. The rising or falling edge of the reference tooth must occur between the same two crankshaft teeth each cycle. The EPT ENC VI can be configured to track 360 or 720 degrees depending upon the location of the reference tooth. When tracking 360 degrees, the reference tooth is located on the crankshaft, yet is wired to the CamSig input of the EPT VI. When tracking 720 degrees, the reference tooth is located on the camshaft. Encoder style patterns are a very common form of engine position tracking in both production and research engine control systems.

In production systems, an encoder pattern will typically consist of a VR sensor looking at a relatively low resolution crankshaft trigger wheel of 4 to 16 teeth. The camshaft sensor may be a VR sensor or hall-effect sensor looking at a single tooth on the cam. For this setup, the rising or falling edge of the cam signal should occur as close as possible to the midway point between two crank signals. This ensures that the cam signal edge will repeatedly occur between the same two crank signals in the presence of crankshaft acceleration. The system designer should also ensure that the camshaft lash due to stretching of the camshaft belt or chain during acceleration or deceleration will not cause the cam signal to move with respect to the crank signals by more than half of the crank tooth spacing. For this reason, production systems will use a low resolution crank trigger wheel. The rising or falling edge of the cam sensor signal may be used as long as the signal is inverted properly within the LabVIEW FPGA block diagram to present a rising edge to the EPT VI CamSig input.

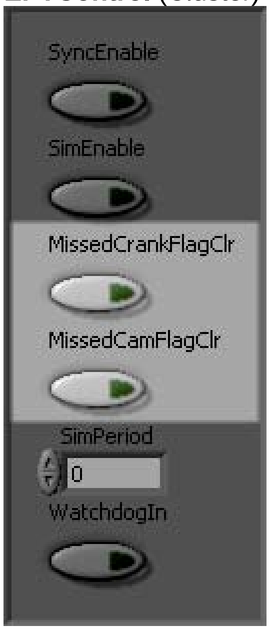
Optical encoders are a common source of signals for this pattern type in research applications. A single optical encoder will have at least three different outputs named A, B and Z. Signals A and B are quadrature encoded 90 degrees out of phase, while Z is a single reference pulse per 360 degrees rotation of the encoder shaft. Signal A or B may be wired to the CrankSig input of the EPT VI while signal Z must be wired to the CamSig input. The designer must remember that signals A and B are equally phased. One or the other must be selected to align with a known location of the crankshaft or camshaft. Encoders having pulse-counts of 360 or 720 pulses per rotation are common for research engine control applications. Although any pulse count may be used. The EPT ENC VI will then extrapolate this to approximately 0.1 CAD.

If the optical encoder is mounted to the crankshaft, then NCT should equal the encoder pulse-count and STROKE should equal 2 (2-stroke). This setup will track 360 degrees. Four-stroke engines may still be controlled under this setup, however, wasted spark ignition must be implemented as well as batch fueling. The highest possible crankshaft position accuracy will be achieved, since the encoder is attached directly to the crankshaft.

If the optical encoder is mounted to the camshaft, then NCT should equal the encoder pulse-count divided by two, and STROKE should equal 4 (4-stroke). This setup will track 720 degrees. With this setup, crankshaft positional accuracy may suffer under engine acceleration and deceleration due to camshaft belt or chain stretching. Nonetheless, it is still a popular method for research applications, especially if engine operation will primarily be steady state.

With encoder patterns, position 0 and tooth 0 correspond to the first tooth following the rising edge to the CamSig input.

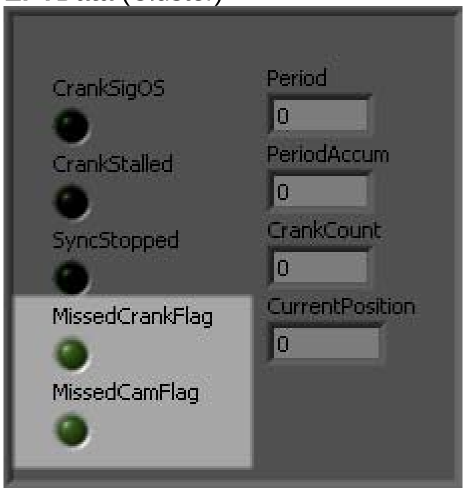
EPTControl (Cluster)



MissedCrankFlagClr (boolean): When TRUE, the MissedCrankFlag within the EPTData cluster will be cleared.

MissedCamFlagClr (boolean): When TRUE, the MissedCamFlag within the EPTData cluster will be cleared.

EPTData (Cluster)



MissedCrankFlag (boolean): Set to TRUE upon the detection of a CamSig rising edge while the CrankCount value has not yet reached the expected value. In other words, the Cam tooth has been detected sooner than expected. This condition causes a loss of sync. Re-sync is not allowed until the flag is cleared by setting MissedCrankFlagClr to TRUE.

MissedCamFlag (boolean): Set to TRUE upon CrankCount being incremented past the expected value for the location of a CamSig rising edge before the CamSig rising edge is detected. In other words, the cam tooth was not received when expected. This condition causes a loss of sync. Re-sync is not allowed until the flag is cleared by setting MissedCamFlagClr to TRUE.

Examples

The following screen capture in Figure 11 shows a LabVIEW FPGA block diagram demonstrating the interface between EPT VIs and fuel/spark VIs. No external signals are wired to the EPTInSig cluster, thus requiring simulation of these signals. However, those signals may be provided from the AD Combo or VR/Hall Module Kits. This FPGA application is entirely contained within a single cycle loop, clocked at the required 40 MHz. Notice that the EPT VI provides the FuelSparkSupervisor cluster to be wired directly to the compatible fuel and spark VIs. Refer to the LabVIEW FPGA documentation for details about configuring cRIO I/O pins. A similar example VI is provided for any EPT, Fuel or Spark product ordered from Drivven.

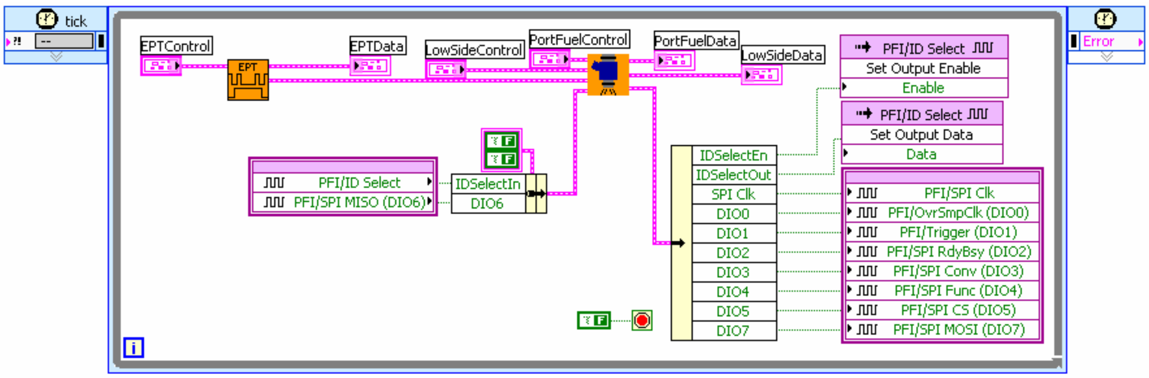


Figure 11. LabVIEW FPGA Block diagram example.