SSI-4 Simple Sensor Interface 4 Channel
User Manual

1. Overview

The SSI-4 device is a simple sensor interface device to add 4 inputs to an MTS Log Chain. The SSI-4 may also be used as a stand-alone 4 channel MTS compatible input device (see Chapter 2 for more details).

Each of the four inputs of the SSI-4 can be user configured for different functionalities.

The following tables show the functionality of each of the 4 inputs of the SSI-4 (the default factory settings of the SSI-4 are highlighted:

Input	**Function 1**	**Function 2**	**Function 3**	**Function 4**
Channel 1	***RPM (programmable Range, default 0..10230 RPM, 4 Cylinder)***	Frequency (straight frequency, Speed sensor)	External 0..5 Volt	
Channel 2	Duty Cycle	Frequency (straight frequency, Speed sensor)	***External 0..5 Volt***	
Channel 3	Ignition Timing	Frequency (straight frequency, Speed sensor)	***External 0..5 Volt***	RPM derived from VR Sensor and Trigger wheel (programmable Range and wheel characteristics)
Channel 4		Frequency (straight frequency, Speed sensor)	***External 0..5 Volt***	

The SSI-4 also can act as a power supply for user supplied external sensors. The 5V output of the SSI-4 can supply up to 300mA of current.

1.1 Differential Inputs

The SSI-4's external connections are differential. This means that each input channel has 2 input terminals. A + terminal and a – terminal. This is to eliminate ground offsets in the signal. Many times the ground point of a sensor is at a different ground than the SSI-4. Because an electronic device can only measure a voltage referenced to it's own ground, differences in grounding can introduce measurement errors. The SSI-4 measures the sensor signal's ground with the – input and them measures the difference between the + and the – input. This way it "recreates" the sensor signal's own ground reference as if this input were referenced directly to that sensor's ground. The common mode rejection range is the maximum voltage this ground reference input can differ from the SSI-4 ground.

The (–) input is NOT a ground itself. It is a ground reference input.

2. Specifications

Power

Power requirements	8-36 Volt / 50mA [1]
Power reversal protection	Yes
External Sensor power	5V (+- 2.5%), 300mA max.

Serial Communication

Serial Port Speed	19.2 kbit/sec
Packet/Logging Speed	81.92 msec/sample packet
Sample Resolution	10 bits (0..5V at 0.1% resolution)

Input Specifications

Number of Channels	4
Input measurement range	0..5V
CHx+ max input voltages	- 22.5 Volt to +300 Volt
CHx- max input voltages	- 22.5 Volt to +27.5 Volt
Common Mode Rejection Range	-22.5 Volt to +22.5 Volt
Input threshhold for pulsed Signals	2.5V
Max Frequency	15 kHz[2]
Input Impedance	1 MOhm
VR Max AC Voltage	160 Vpp
VR Min Detection Voltage	700 mVpp

Temperature

Max Operating Temperature	-20 to +80 deg Celsius

Mechanical

Size (W x L x H)	133 x 65 x 26 mm
Weight	114 grams

Note 1:
Supply current specified does not include external sensor current supplied by 5V output.

Note 2:
Sum of all frequency/Timing/Duty Cycle signals connected should not exceed 15 kHz.

The Innovate Log-Chain concept

LogWorks 2.0 has the capability to log, display and analyze up to 32 engine parameters. Most users will use less though. Each of the MTS components reads between 1 and 6 engine parameters. To interface a multitude of MTS components to LogWorks with a single connection, the Innovate LogChain concept was introduced.

The SSI-4 can be used as a MTS component in a Log-Chain.
Each of the MTS components has two serial ports (except the LM-1, which has only one). One serial port is designated as IN-port, the other as OUT port. The OUT-port of one device is connected to the IN-port of the next device and so on. This way devices can be ‘daisy-chained’ to build a log-chain for up to 32 channels total. The OUT-port of the last device is connected to the computer for logging or downloading of logged data.

The device that’s first in the chain is special. It determines the logging sample rate. The first device in the chain sends a data packet containing its channel data (a sample) to the next device (downstream, left to right in the diagram) every 81.92 milliseconds. The next device appends its data to that packet and hands that packet to the next device downstream and so on. At each device the packet grows in length. The devices in the chain synchronize their sampling of the engine parameters to the packets, so that all the channels in a packet together represent the same instance in time. At the downstream end of the log chain (OUT-port of the last device) a computer or external logger can be connected to store or display the stream data. The XD-1 display is such a device.

This also means that the complete channel data set is ONLY available at the end of the log-chain. A datalogger capable of recording the log-chain data-stream therefore MUST be placed at the end of the log-chain. This includes lap-top computers or other loggers.

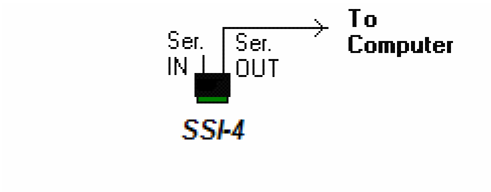
Commands for individual devices are sent ‘upstream’. A device (incl. a computer or an XD-1) can send commands to the devices upstream of itself, but not downstream. Commands can include start-stop recording, calibration/configuration commands and so on. Only the device directly upstream of the command originator of course will receive the command. This device then decides, depending on the command, whether to execute the command and whether to pass it on. An example of a case where the command is executed but not passed on is the start-stop record command. The first upstream device capable of logging internally will execute the command, but not pass it on.

As said before, the first device is special because it is the synchronization source for the entire chain. By plugging its IN-port with the supplied terminator connector, a device can detect that requirement when it powers up. The terminator connector just connects the transmit and receive line of the IN-port together. Each device sends a special command out on it’s IN port when it powers up. This command is ignored and not passed on by any device if received on it’s OUT port. If the sending device immediately receives that command on its IN-port again, because the terminator is plugged in, it assumes it is the first and special device in the chain. The LM-1, having only one serial port, is ALWAYS a special device and MUST be connected to the beginning of the chain.

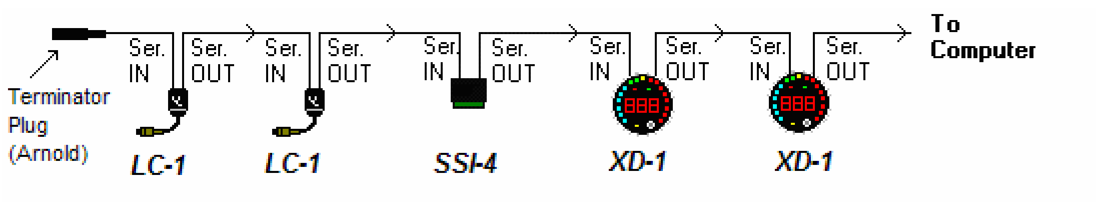
The following are some examples of Log-Chains using the SSI-4 and other MTS devices.

NOTE: The SSI-4 does NOT need a terminator plug on it’s IN port. It automatically detects if another device is plugged into it’s IN port and terminates the IN port if nothing is plugged in.

2.1 Log-Chain of 4 channels consisting of SSI-4 alone.



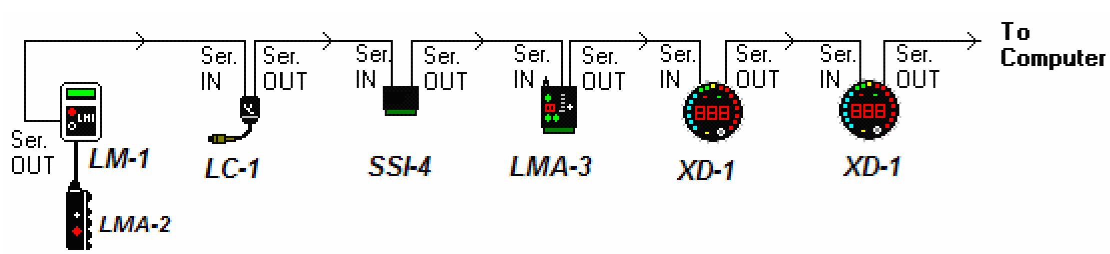
2.2 6-channel Log-Chain example with 2 AFR channels.



Notice that the LC-1's are connected BEFORE the first SSI-4. LC-1's should always be connected before the first SSI-4.

2.3 16-Channel Log-Chain example

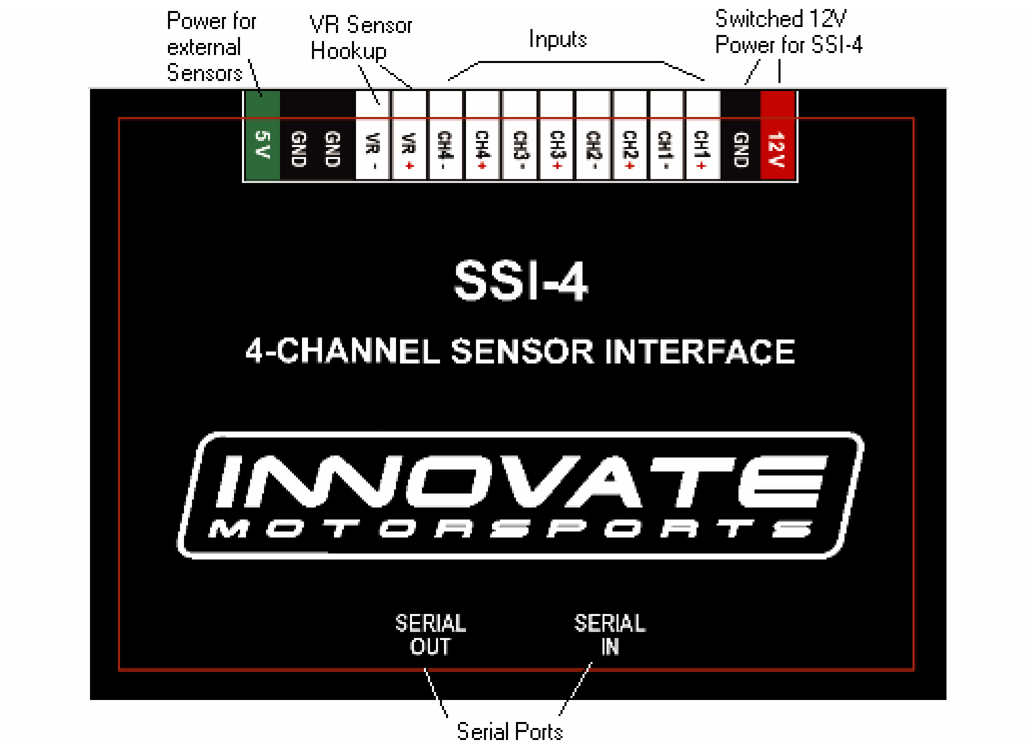
The example chain consists of a LM-1/LMA-2, a LC-1, a SSI-4, a LMA-3 and 2 XD-1's. In this case the chain has 16 channels (6 from LM-1, 1 from LC-1, 4 from the SSI-4 and 5 from the LMA-3).



Devices attached to the LM-1's analog input count as being part of the LM-1's 6 channels. They don't count extra. XD-1's do not contribute any channels, so you can add as many as needed.

3. Connecting the SSI-4

The SSI-4 looks like this:



3.1 Connecting power

Connect switched 12V power (switched on when the cars ignition system is on) from the car to the terminal marked 12V on the SSI-4 connector.
Connect one of the terminals marked GND to a good ground on the car. The engine block will supply a good ground connection.

3.2 Connecting external sensor signals

For each external connection you can connect the external sensor's output to the CHx+ connection. Connect the CHx- connection to the ground of the sensor. Make sure the sensor output signal does not exceed 5V. The SSI-4 is protected if sensor signals exceed that (up to 300V for most inputs), but it cannot measure beyond a 5V signal.

3.3 Powering external sensors

At the connection marked 5V you can connect external sensors. External sensors don't HAVE to be powered by the SSI-4. The 5V output is a convenience for external sensors when no 5V supply is available. The 5V supply can power sensors with a total power consumption of up to 300mA.

4. RPM measurement

4.1 RPM Measurement basics

Most RPM measurement methods use the ignition system of the car as a convenient source of RPM dependent pulses. Other methods use a TDC sensor (one pulse per rotation), cam sensor, or fuel injection pulses (number of pulses/rotation is dependent on the fuel-injection system). Some actually measure the AC frequency created by the car's alternator.

Because the number of pulses per crank rotation is dependent on the ignition system and engine type, a universal RPM measurement method must be adaptable to the different environments encountered. The typical ignition system consists of an ignition coil, a coil driver that switches current to the coil on and off, and a distributor. When current is switched on to the coil, the coil stores energy in its magnetic field. When the current is switched off, that energy gets discharged at a very high voltage pulse on the coil’s secondary winding, creating a spark.

A capacitive discharge ignition system (CDI) uses a capacitor to store the spark energy. The capacitor is charged to about 400V and then rapidly discharged over the ignition coil's primary winding. The coil thus only acts as transformer and does not store energy (and can therefore be smaller). The advantage of a CDI system is a very high and fast rising spark voltage (less susceptible to spark fouling). The weakness of the CDI system is the very short duration spark, which might not be long enough to ignite the mixture. Multispark ignition systems try to overcome the inherent weakness by creating multiple spark pulses over some degrees of crank rotation to increase the likelihood of igniting the mixture. The distributor switches the spark voltage to the appropriate spark plug.

4.1.1 Four-Stroke Engines

On a typical 4-stroke engine each spark plug fires once for every two crank rotations. The coil on a distributor-equipped 4-stroke has to create sparks for every cylinder. The number of ignition pulses per crank rotation in this case is the number of cylinders divided by 2.

Some engines have one coil for every 2 cylinders instead of a distributor. The coil fires two spark plugs at the same time. One spark is wasted because it fires one cylinder at the end of its exhaust stroke. Therefore, this system is called a Waste Spark System. Each coil of a Waste Spark System fires once for every crank revolution.

Other distributor-less 4-stroke engines use one ignition coil for every spark plug. This ignition system fires each coil once for every 2 crank revolutions.

Coil-on-Plug ignition systems actually incorporate the ignition coil in a module that plugs directly onto a spark plug and do not have a spark plug wire.

4.1.2 Two-Stroke Engines

On a 2-stroke engine there is a spark for every crank rotation, so the spark frequency doubles compared to a 4-stroke.Very few multi-cylinder 2-strokes have distributors. For those that do, the number of ignition pulses per crank rotation is equal to the number of cylinders. Most two-stroke engines have one coil for every cylinder. The coil fires once for every crank revolution, the same as on a 4-Stroke Waste Spark system.

4.1.3 Rotary Engines (Wankel Engine)

A rotary engine consists of a roughly triangle shaped rotor rotating in a roughly elliptical chamber. The three spaces left between the chamber and the rotor go through the four cycles of a four-stroke engine for each rotation of the rotor. A single (or dual) spark plug at a fixed position in the chamber ignites the mixture of each space in sequence. Therefore, a rotary engine requires 3 sparks for every rotation of the rotor. The mechanical power from the rotor is coupled to an eccentric gear to the output shaft. This gear has a 3:1 gear ratio and the output shaft therefore rotates 3 times faster than the rotor. The output shaft is the equivalent of the crankshaft on a piston engine. Because RPMs are measured conventionally as the rotations of the crankshaft, the rotary engine requires one spark for every 'crankshaft' rotation, the same as a two-stroke engine.

4.2 How the SSI-4 determines RPM

4.2.1 Measurement Method on Channel 1

The SSI-4 measures RPM not by measuring the number of pulses over a time period, as a tachometer does. That measurement would be too slow to provide adequate correlation between input channels. Instead the SSI-4 measures the time between input pulses and from that calculates RPM for each pulse measurement.
This measurement method has a few caveats though:

1. If the RPM pulse signal is derived from the ignition signal, a multi-spark ignition system will trigger the measurement multiple times for each pulse. This throws the measurement off because the SSI-4 does not know if the pulses are for each ignition event (one per cylinder cycle) or because of multispark. This is specially problematic because the number of multispark pulses also varies with RPM in a lot of ignition systems. Fortunately many multispark ignition systems output a tach signal with only one pulse per engine cycle. But some, notably Ford EDIS systems, output all pulses and therefore may require a special tach adapter.

2. Odd fire engines, like V-Twin motorcycle engines and odd-fire V6 engines have ignition pulses that are not evenly spaced. For example a 60 degree V-Twin running at 10 degrees ignition advance will fire cyl. 1 at 10 degrees BTDC. Then fire cyl. Two 420 degrees later at 410 degrees. Then fire cyl 1 300 degrees later at 710 degrees. This means the ignition pulses sent to the SSI-4 are alternating between 420 and 300 degrees apart and therefore the time between pulses alternates. The SSI-4 therefore measures the times between ALL pulses for a complete engine cycle (2 rotations) and averages the times between them.

4.3 Connecting an RPM signal (Channel 1)

- Connect the RPM signal to the CH1+ input screw terminal.
- Connect the CH1- signal to the ground of the RPM signal source. For example the ground of the ignition system <u>at the ignition box</u>, not where it’s ground wire connects to the frame or engine.

4.4 Getting an RPM Signal From a VR sensor Trigger wheel

A lot of modern cars use Trigger wheels to indicate to the ECU what crank angle the engine currently runs at. These trigger wheels are made of steel and have varying number of teeth. The most common are the Ford Trigger wheel with 36 teeth spaced 10 degrees apart and one tooth missing. Another common one is the Bosch Motronic wheel with 60 (spaced 6 degrees apart) and 2 teeth missing. But many other combinations are possible. The trigger wheel is either attached to the balancer, or it can also be part of the flywheel.
The SSI-4 works with all VR sensor wheels up to 60 teeth with either 1 or 2 teeth missing or 1 extra tooth.
A Variable Reluctance sensor (VR sensor) is used to detect the teeth passing by. The missing, or extra tooth is used as TDC marker. The missing tooth does not necessarily be at TDC, but can be offset by a certain number of degrees. This offset is important for ignition advance measurement, but not for RPM measurement.
The SSI-4 has a built-in amplifier and detector for VR sensors. The characteristics of the trigger wheel need to be programmed into the SSI-4 to correctly detect RPM.

For details on connecting VR sensors see chapter 6.1.

The SSI-4 can measure RPM from a VR sensor trigger wheel on Channel 3. Channel 1 can then be used for other things.

NOTE:
When a VR sensor is connected to the VR+ and VR- inputs of the SSI-3, the CH3+ and CH3- terminals MUST be left open and unconnected.

5. Measuring Ignition Advance

Warning:
Measuring ignition advance is NOT a simple plug-and-play process. The variables are many and you need to know what you are doing to do it right. Read this chapter multiple times before attempting this and try to understand what you are measuring.

The SSI-4 expects the spark reference pulse on input 1 and the crank reference pulse on input 3.

Input 1 is simultaneously still used to measure RPM, and MUST be set to measure RPM.

The SSI-4 can measure ignition advance between 10 degrees ATDC to 50 degrees BTDC. ADTC numbers will be negative, BTDC numbers will be positive. The LogWorks equivalents are 0V = -10 degrees, 5V = 50 degrees.

Ignition advance is typically measured in degrees. This is the number of degrees before Top-dead-center of a piston where the spark fires.

When the spark in an engine fires the mixture in the combustion chamber starts the burn process. Because it takes time for the fire to consume the mixture, it has to be lighted before the piston hits top dead center. During that burning process the pressure and temperature rises. The pressure and temperature rise results not only from the energy released by the burning mixture, but also the piston is still moving up, compressing the burning gas. At some point in this process the pressure in the cylinder peaks and then falls off. The position of this pressure peak (in crank angles) depends on the engine geometry (bore-stroke ratio, stroke-rod length ratio and so on), but NOT on engine load or RPM. For many engines the ideal peak pressure position to extract the maximum energy is between 14 and 20 degrees ATDC.

The time the mixture takes to burn is dependent on many variables. AFR, mixture density, temperature and so on are some of the variables. The point of ignition advance is to time the spark such, that the peak pressure point is reached at the ideal position. Earlier or later looses power.

An engine typically does not have a “crank degree” sensor output of sufficient resolution. Therefore ignition advance must be measured as a time measurement. An engine crankshaft rotates at 360 degrees per revolution. So, by measuring the time between the spark pulse and a reference pulse, the ignition advance time can be calculated.

For example if the reference pulse is at a 90 degree crank angle and the spark happens at 20 degrees BTDC at 6000 RPM, the engine rotates at 36000 degrees per second. So, the time difference between spark pulse and reference pulse is 0.003055 seconds.

Most modern EFI systems have trigger wheels that create reference pulses through a hall effect or variable reluctance sensor. These trigger wheels look like toothed gears with one or two teeth missing (some instead have extra teeth).

Some systems also have only a single magnetic trigger reference from the flywheel or balancer and use the starter ring gear to provide extra pulses. The extra pulses are needed by the ECU to determine the exact crank angle when to fire the sparks for the different cylinders.

The SSI-4 is not concerned with firing multiple cylinders, but only with the timing of one cylinder (typically cylinder 1). Therefore it does not need the additional pulses, but can identify the reference trigger from each.

Another concern is the “phase” of the pulses. The timing can be measured either from the rising or falling edges of the spark pulse to the rising or falling edges of the reference pulse. Which pulse edge for each has to be known to allow accurate measurement. Very often this can be only determined by trial and error. This means you have to go through all four possible combinations until you measure the correct advance, verified with a timing light.

For this reason the use of the inductive clamp as RPM source is NOT recommended for spark advance measurement, because it’s phase is indetermined and changes depending on which way around you use the clamp.

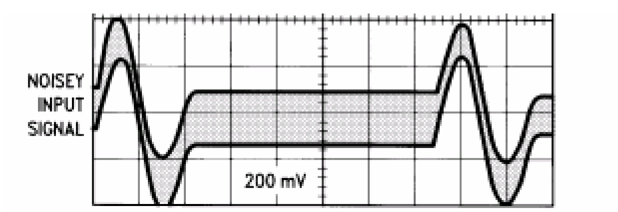
For example if the source for the spark pulse is the negative side of the ignition coil (inductive ignition), the negative side of the coil goes to ground (negative edge of pulse) to charge the coil. When the coil discharges (spark happens) the voltage rises to several hundred volts and then returns to 12V. In this case the spark pulse would use the rising edge.

The same is true for the trigger pulse from the trigger wheel. Depending on the sensor used, the output pulses can be negative or positive. This can either be found out with an oscilloscope or by programming the SSI-4 for one way or the other and finding out which is the correct one.
The tryout should be done at different RPMs, because under some circumstances you could get a correct reading at idle, but a shift at a different RPM.

5.1 Using VR sensors as TDC reference input for the SSI-4

Variable reluctance sensor (VR sensors) are used a lot in modern cars to detect cam or crank position. They basically react to the change in magnetic field when a gear tooth of an iron or steel geared wheel passes under them. As the gear tooth approaches the sensor, it outputs a positive voltage that changes to a negative voltage at mid-tooth. As the tooth moves away from the sensor, the voltage decays back to zero.

Example voltage trace of a VR sensor output:



NOTE:
VR sensor’s output voltage is dependent on the speed of the gear-teeth passing under them. They are typically designed to output a minimum voltage only at cranking speed. You can’t measure the output voltage by rotating the engine by hand and using a multimeter.

VR sensors have a positive side, and a negative side. The sensor has to be connected correctly. Very often the negative side of the VR sensor is connected to ground inside the ECU. You can measure that with an Ohmmeter between the VR sensor input pins of the ECU and ground with the VR sensor disconnected. The negative VR sensor ECU wire will be grounded. Of course, the measurement has to be done with power off to the ECU.

5.1.1 Connecting and using a VR sensor with the SSI-4

The SSI-4 has a built-in VR sensor amplifier. To use it:

- Connect the VR sensor positive lead to the VR+ terminal on the SSI-4.
- Connect the VR sensor negative lead to the VR- terminal of the SSI-4.

The SSI-4 can be connected to the VR sensor at the same time as the ECU. Just splice in the SSI-4 wires. The ECU will still be able to read the VR sensor.

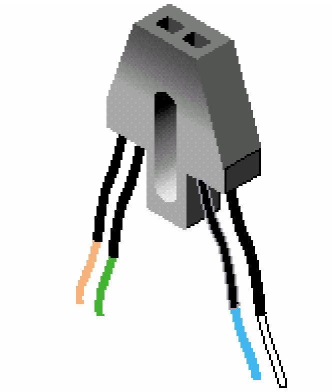
NOTE: The Input Terminals IN3+ and IN3- MUST be left open if the VR+ and VR- inputs are used.

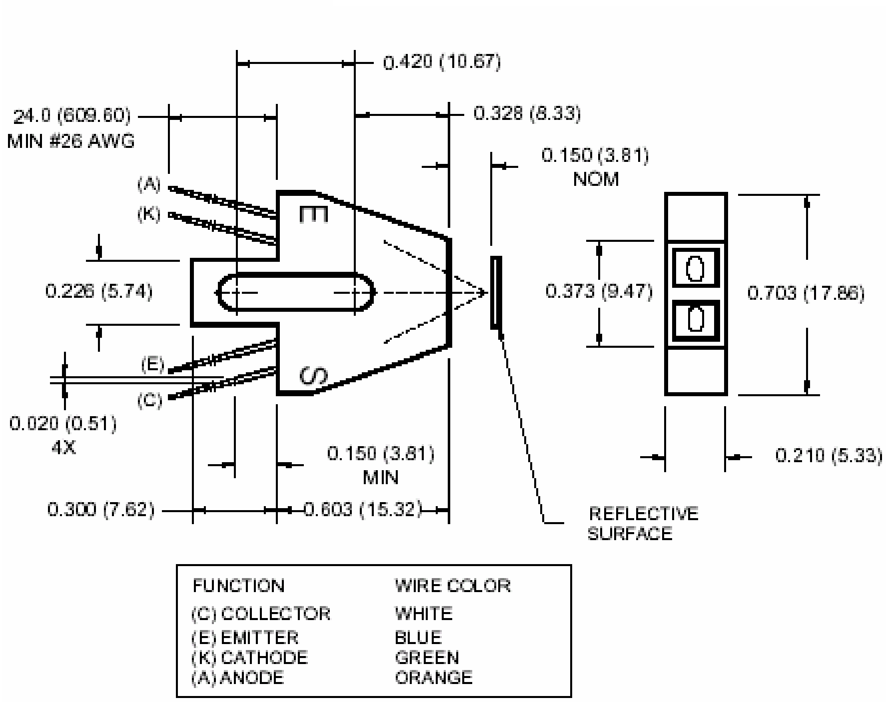
The SSI-4 MUST be programmed for positive pulse edge when using the internal VR sensor amplifier (See Chapter 9, Programming the SSI-4 for details).

5.2 Making your own optical reference pulse sensor

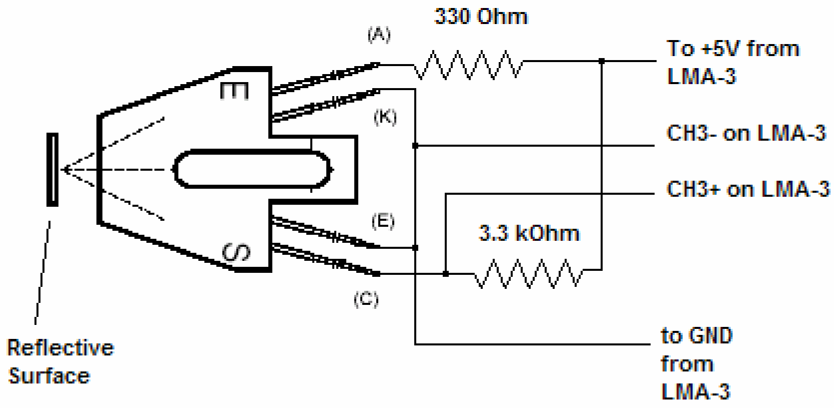
The device to be used is a Fairchild reflective optical sensor type QRC1133. This device contains a infrared LED to shine an infrared light beam on a mark on the balancer or flywheel and also contains a photodiode to detect the reflected light. The device can be ordered from: www.digikey.com Part Number QRC-1133-ND.

This device looks like this:





To use it you also need two resistors (1/4W). One resistor is 330 Ohm, the other 3.3 kOhm. The hookup schematic to be used is this:



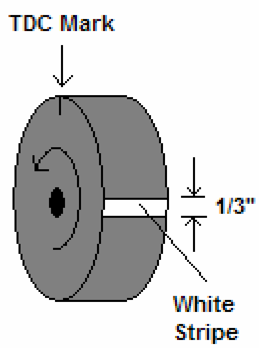
Paint the balancer or flywheel surface flat black so as to reflect minimal light.

Turn the crank so that the engine's timing marks line up at '0'. On some balancers, there is a single mark with multiple degrees marked on a tab attached to the block or timing cover. Other balancers are marked with multiple degrees and the tab is a single pointer. In either case, line the markers up to '0' or 'TDC'.

Note: It is generally a bad idea to rotate the crank more than a few degrees in the direction opposite of its normal rotation. If you pass the '0' or 'TDC' point while rotating the crank, it is preferable to 'continue around', rather than to "back up".

With the engine aligned at TDC, mount the sensor, as shown above, where space allows. Mount the device so that it's front edge is about 0.15" (3.8 mm) from the flywheel/balancer. The LED shines infrared light on the flywheel balancer, but the light is absorbed by the black surface.

Mark the balancer at the point where the sensor is pointing with a pencil or a Sharpie marker..



Once marked, turn the crank, as necessary, to allow access to the marked portion of the balancer. Paint a ¼" – 1/3" wide white or silver mark on the balancer at the marked point, as shown above.

When the LED shines on the white stripe, light is reflected and the photodetector is on, drawing current through the 3.3 kOhm resistor. The voltage at the CH3+ connection should be less than 1 Volt. If the voltage is higher, replace the 3.3 kOhm resistor with a higher value.

. So the photodetector in the device is off and the CH3+ connection should be between 3 and 5V. If the voltage is lower, replace the 3.3 kOhm resistor with a lower value, but don't go below 1 kOhm.

The device will output a pulse with the NEGATIVE edge at the beginning of the mark.

5.3 How the SSI-4 measures ignition advance

Ignition Advance is how many crank degrees before (or after) TDC the ignition fires. This means the measurement system must know where TDC is and when the spark fires. There's no sensor on a car that directly measure crankshaft degrees. Therefore the SSI-4 needs to measure RPM and the time difference between the TDC mark and the ignition firing.

Example:
At 6000 RPM an engine rotates 100 times/second. This means the crankshaft rotates 36000 degrees per second. So, if the spark fires 1 millisecond before TDC, the ignition advance is 36000 degrees/sec times $1/1000^{th}$ second, or 36 degrees.

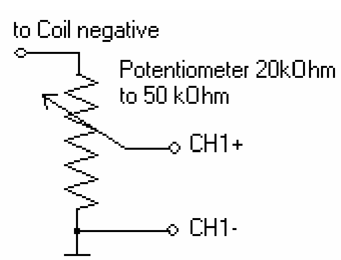
The timer resolution of the internal timers of the SSI-4 are 2 microseconds. This means, at 6000 RPM the theoretical minimum resolution in crank degrees it can resolve would be 0.018 degrees. At 12000 RPM it would be 0.036 degrees. This is much smaller than needed in reality.

5.3.1 Measurement Details

To determine RPM, the SSI-4 measures the time it takes the reference tooth to pass by. It passes by once per revolution, and thus the SSI-4 measures the time of one revolution. The reference tooth is either the tooth after the missing tooth (or teeth) on a missing-tooth trigger wheel, the extra tooth on a extra-tooth trigger wheel or simply the mark tooth if only one tooth wheel or mark is used (called the Redneck Trigger, because it has only one tooth).

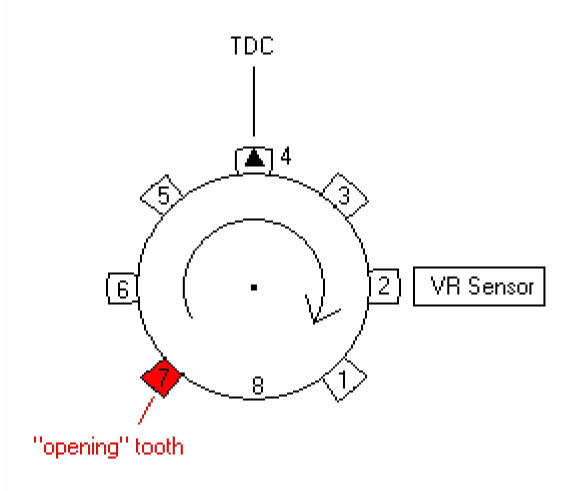
The SSI 4 also calculates which tooth is the last tooth before the measurement window (50deg BTDC to 10deg ATDC) opens. This is the "opening" tooth. All spark events that happen before the "opening" tooth passed by, are ignored.
In addition it calculates, based on the last measured RPM from the previous rotation, what minimum time after the "opening" tooth happened, a 50deg BTDC spark can happen. All spark events that happen faster than that are also ignored. So the first spark event happening after the measurement window opens, is used to calculate ignition advance. All further spark events after the measured one are ignored until after the opening tooth passes by again.

For this to work, the RPM signal on Input 1 MUST have either a negative edge or positive edge when a spark happens. A RPM signal on Input 1 that does not correlate to a spark event can't be used. This is often the case if an RPM signal generated by an ECU is used. In that case the RPM signal needs to be tapped of the coil negative or the ignition drive signal. In the case of getting the RPM signal from coil negative, typically a positive edge happens when the coil fires. This assumes a regular inductive, not a CD ignition system. CD ignition systems typically do have an RPM output, but the polarity of the pulse (which edge coincides with the spark event) depends on the manufacturer and device model.
On some dwell controlled ignition systems, like GM HEI, very often a potentiometer needs to be used to attenuate the RPM signal so only the TRUE spark event is measured, not other edges in the waveform. Below is an expample on how to connect such a potentiometer:



The importance of programming the correct pulse edge for both, the TDC reference signal and spark signal is illustrated below:

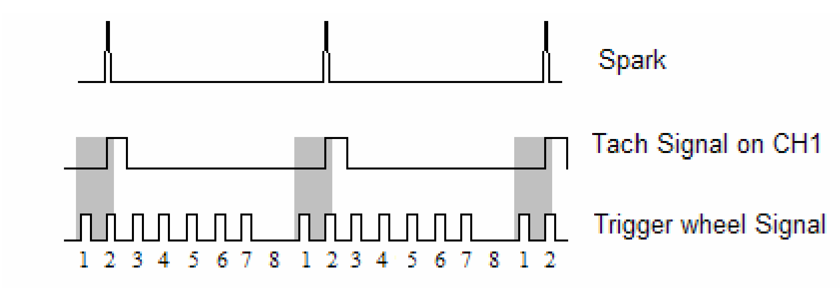
We assume a 8 tooth trigger wheel (teeth 45 degrees apart) with one tooth missing. The wheel is installed with the missing tooth at 180 degrees from TDC, the VR sensor is mounted at 90 degrees after TDC as in this illustration:



From this we know that the missing tooth (number 8) passes by the VR sensor at 90 degrees BTDC. The missing tooth is 180 degrees before TDC. The VR sensor is offset from that in counter-rotating direction by 90 degrees, so 180 – 90 = 90.
Tooth number 1 can't be used as opening tooth, because it passes by 45 degrees BTDC. Tooth number 8 can't be used because it's not there. So tooth number 7 is used. It passes by 135 degrees BTDC.

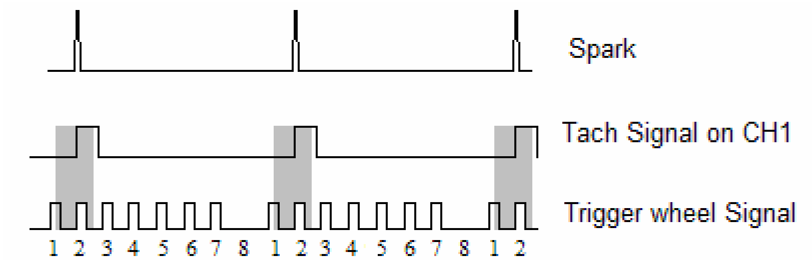
The tooth after the missing tooth or after the extra tooth (if a wheel with an extra tooth is used), is tooth number 1, or the TDC trigger tooth.

Now let's look at the pulses that the SSI-4 would see at 6000 RPM. We asume a tach pulse width of 1 msec, spark at TDC. Tooth reference pulse edge is positive (rising edge) and tach reference pulse has a positive edge at the spark event. The example shows a 2 cylinder engine with one tach output at every spark event.
The "measurement window" of 50 deg BTDC to 10 deg ATDC is shown in gray.



One can clearly see that the falling edge of the tach signal is outside the measurement window. If for example the tach signal contains the spark signal of all sparks of an 8 cylinder engine, the spark event of cyl. 8 instead of cyl 1 could fall into the measurement window and the measurements would be off.

The following example shows what would happen if the wrong edge of the trigger wheel signal is used:



One can see that the measurement window is shifted by the width (or time duration) of the Trigger wheel pulse. Because in most cases that pulse width is fixed, the error translates to varying number of degrees depending on RPM.

To set up the ignition measurement system of the SSI-4 with unknown edge trigger signals, all four possible cases should be examined and verified with a timing light at at least 2 different RPMs:

Case 1	Trigger pulse positive edge	Spark reference positive edge
Case 2	Trigger pulse positive edge	Spark reference negative edge
Case 3	Trigger pulse negative edge	Spark reference positive edge
Case 4	Trigger pulse negative edge	Spark reference negative edge

6. Measuring Frequencies, custom RPM, or speed

The SSI-4 has the capability to measure frequencies on any of the channels. It converts a frequency signal (pulses per second) into a number between 0 and 1023 (or 0..5V) to be logged directly by LogWorks. This is useful for measuring custom RPM ranges, signals from speed sensors or the frequency of MAF sensors with frequency output (as opposed to voltage output MAF sensors).

The range of frequencies that the SSI-4 can measure can be programmed by with LM Programmer. The SSI-4 can be set to any frequency range between 0 and 30 Hz for the full 0..5V range to 0..15 kHz for the full 0..5V output (logging) range.

Also, LM Programmer has convenient conversions built in, so you don't have to calculate the resulting frequency ranges for speed sensing or RPM sensing yourself. See chapter 10.x for details.

A frequency input signal must have an amplitude (voltage range of pulse) between 0.5V at the low pulse point to minimum of 3V and maximum of 40 V at the high pulse range.

See chapter 10 for details on different kinds of Frequency, speed and RPM sensors.

NOTE:
The custom RPM feature will work only for even fire tach signals, not for tach signals that vary their time between pulses during an engine cycle (odd fire engines). Use the input 1 RPM functions instead.

7. Measuring duty cycle

To measure the duty cycle of a signal in channel 2, the input signal must cover the same voltage range as for a frequency signal. Duty cycle is defined as the ratio between the time a signal is active and the total time of the active and inactive time. A signal can be either active high (the event, like injector open, happens when there is a high voltage) or active low (the event happes when the measured signal is at ground or close to it).

Very often the injector duty cycle is to be measured by the SSI-4. A typical fuel injector is connected to 12V on one side, while the other side is connected to ground when the ECU opens the injector. Because the pulse is therefore active when the voltage on the pin is at ground, negative duty cycle is measured.

So called peak-hold injectors (as opposed to saturated injectors), work differently. Their drive signal first goes to ground for a high current opening pulse, then rises to 8-10 Volts for the hold period. Because the SSI-4 sees everything above 2.5V as "high", it will be able to see only the peak period. On some peak-hold systems it is possible to connect the CHx+ input of the SSI-4 to 12V at the injector and connect the CHx- input to the injector signal to still measure correctly. If the above method can be applied, it actually measures positive duty cycle.
But that is not always the case. The LogWorks 2.0 Manual shows an alternative method.

8. Measuring external 5V sensors

Each of the 5 channels on the SSI-4 can be configured to accept input from an external 0..5V sensor. Hookup is very straight forward, with ground going to the '-' input for the channel and the positive sensor signal going to the '+' input for the channel. Raw sensor data can be converted into meaningful units and values using the input configuration features of LogWorks on a PC.

9. Programming the SSI-4 with LM Programmer

To connect the SSI-4 for programming follow these steps:

1. Disconnect any MTS device from the IN port.
2. Connect the 2.5mm to DB 2 computer interface cable into the Serial OUT port. Your computer needs a serial port. If it does not have one, you will need a USB to serial adapter.
3. Power the SSI-4 either from 12V or a 9V Battery (when using a desktop computer).
4. Start the LM Programmer application

The following screen will show up:

The LM Programmer software then shows in its first page the type and version number of the firmware of the device.

9.1 Changing the device name

If multiple SSI-4's are used in a Log-Chain, each MUST be given a unique name so that LogWorks can identify each SSI-4. Just enter a name in the edit box in this page.

9.2 Updating the firmware

Click on the 'Update Firmware' button. You will be presented with a file dialog box that allows you to select a firmware file. Firmware files end with the file extension .dld.
SSI-4 firmware file names start with: SSI4. The first part is followed by a dash, then a V, then the version number without dots.

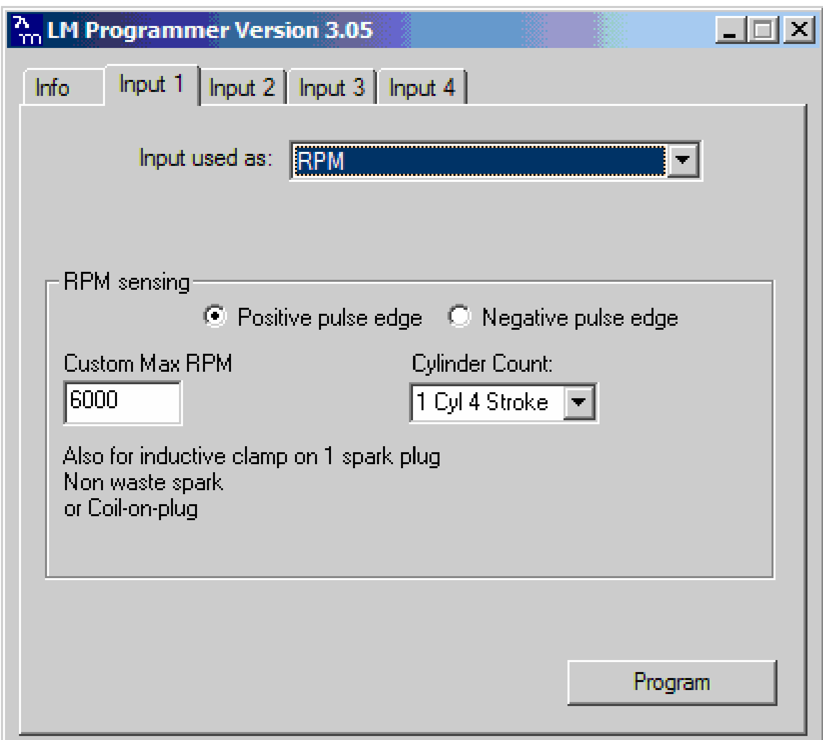
Example: SSI-4 firmware version 1.00 alpha release would have the file name SSI4-V100A.dld
SSI4 firmware version 1.00 would have the file name SSI4-V100.dld

After you opened the firmware file, this new firmware will be downloaded in the SSI-4 device.

9.3 Input Configurations

Click on the appropriate Input tab in the top of the window to configure one of the SSI-4 inputs..
Each Input has different capabilities. Below are details for the setup of each capability.

9.3.1 Measuring RPM (Input 1 only)



The drop-down list at the top of the window allows you to select the different functionality for that input. If RPM is selected, the area below the functionality selection shows as above.

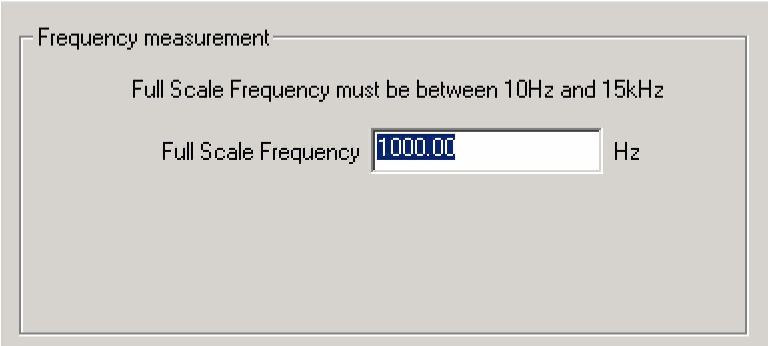
The positive edge/negative edge selection is ONLY important if this input is also used as spark reference signal for ignition advance measurement.

Select the cylinder count in the appropriate drop-down list.

On the left edit box you can specify the max RPM for this measurement channel. In the example case the max RPM is 6000. This means that in LogWorks 6000 RPM is equivalent to 5Volt. This allows LogWorks to have a higher RPM resolution (~ 6 RPM per step instead of 10 RPM when the range is 0..10230 RPM). This functionality is also available for Inputs 4 and 5.

9.3.2 Measuring Frequency (all Inputs)

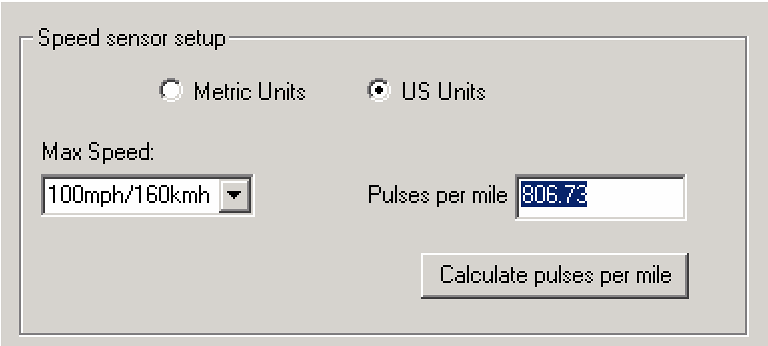
The center section of the window changes to this:



You can enter any frequency between 10 Hz and 15000 Hz as full scale frequency. SSI-4 measures the frequency with a resolution of 0.1 % of the full scale frequency specified. So in LogWorks 0 Hz is always 0 Volt, and the full-scale frequency is equivalent to 5 Volt.
This functionality is also available for Inputs 4 and 5.

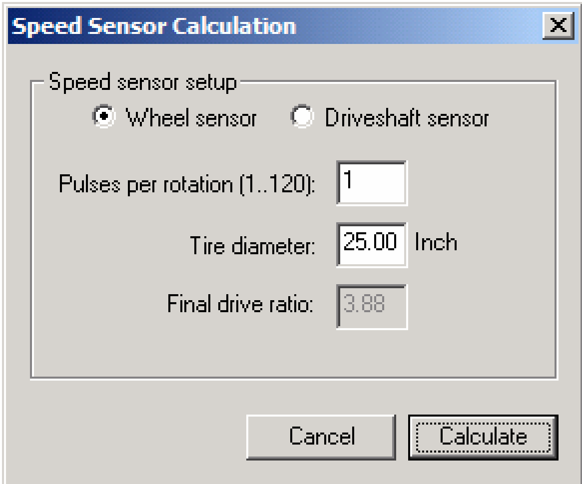
9.3.3 Measuring Speed (all Inputs)

Select the Speed sensing function in the topmost drop-down list. The center section of the window changes to:



With the radio buttons you can select to use metric (km/h) or US (mph) units. In the left drop-down list you select the max speed to be measured. The SSI-4 measures the speed with a resolution of 0.1 % of the selected max speed.

In the right edit box you enter the pulses per mile the speed sensor produces. Speed sensors are typically pulse sensors mounted either on the drive-shaft or wheel. To calculate the pulses per mile (or km/h) click on the calculate button:



Select if you use a drive-shaft sensor or a wheel sensor. Enter the pulses per rotation created by the sensor either as driveshaft rotation or wheel rotation. You also need to enter the wheel diameter, and in case of a drive-shaft sensor, the final drive (differential) ratio.

The LM-Programmer will calculate the pulses per mile (km) for you.

This functionality is also available for Inputs 4 and 5.

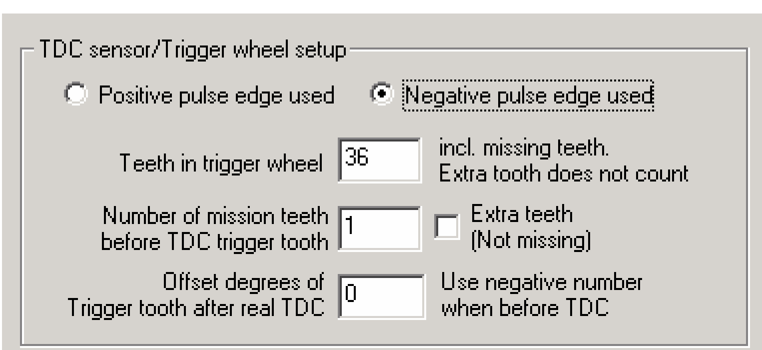
9.3.4 Measuring Duty Cycle (Input 2 only)

Input 2 has the capability to measure duty cycle. See chapter 7 for details.

9.3.5 Measuring Ignition Timing (Input 3 with Input 1)

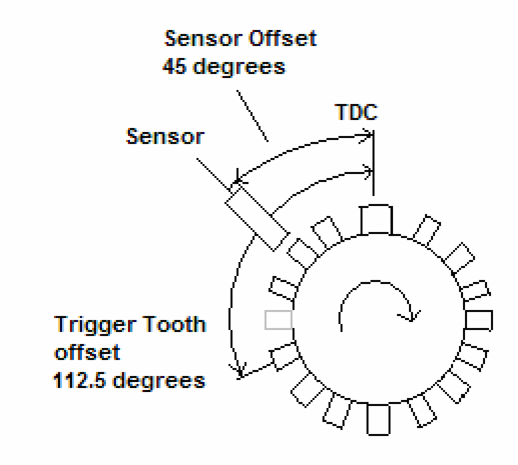
To measure ignition advance, Input 1 MUST be configured for RPM measurement.

When selecting ignition timing (See chapter 5 for details) for input 3, the center of the window changes to this:



Select the trigger wheel characteristics. The trigger tooth is the tooth after the last missing tooth (if missing teeth), or the extra tooth when the wheel has extra teeth. If only one pulse is used, the missing teeth/extra teeth input is ignored.

To enter the offset in degrees, measure the offset (in degrees) after TDC after the last missing tooth. Also measure the offset of the sensor from TDC. Subtract the sensor offset from the tooth offset to get the real offset of the Trigger tooth to be entered. The following picture shows an example:



In this case the offset of the Trigger Tooth is 112.5 degrees (passes TDC in 112.5 deg after TDC). The sensor is mounted at 45 degrees after TDC (After TDC here is opposite to rotation direction). So the complete real offset from TDC is 67.5 (112.5 – 45) degrees after TDC.

Another method to measure the offset is to set the engine at TDC. Then rotate the engine by hand until the first tooth after the missing tooth or extra tooth is centered under the sensor (VR sensor case) or the hall effect sensor's or optical sensor's output changes as this tooth rotates to under the sensor. Measure the number of degrees you had to rotate the engine to accomplish that,

The built-in VR sensor amplifier of the SSI-4 creates a positive pulse edge when the center of the trigger tooth passes under the sensor. Hall effect sensors sense the presence of a tooth or magnet and their output goes from 12V or 5V to 0V when the magnetic field is high enough (negative edge). Depending on the sensor, they can also output a low voltage when no magnetic field is detected and output 5V or 12V when detecting a magnetic field. In that case positive pulse edge needs to be used. Optical sensors can be treated similarly to Hall effect sensors with regard to timing measurement. They sense the presence or absence of a reflecting surface instead of a magnetic field. But they also output a low or high voltage at the passing of a reflective mark.

On Ford EDIS systems for example the correct setup is simple:

On all EDIS installations, with a 36 tooth trigger wheel with 1 missing tooth, the missing tooth of the wheel is directly opposite (180 degrees) the VR sensor when the engine is at the above TDC value. This means your crank wheel needs to be aligned on the damper such that when the engine is N degrees BTDC, the missing tooth is located 180 degrees away from the VR sensor. This also means the "trigger tooth" passes TDC 170 degrees BTDC.

Cylinders	**Sensor Position relative to TDC of Cyl. 1**	Programmed Offset
4	90 deg BTDC	90 – 170 = -80
6	60 deg BTDC	60 – 170 = -110
8	50 deg BTDC	50 – 170 = -120
10	26 deg BTDC	26 – 170 = -144

This assumes of course that the trigger wheel and Sensor is positioned exactly at the correct degrees as indicated.

Crank Trigger Setups:

Many crank trigger setups use magnets in the balancer, crank pulley or flywheel to trigger a hall effect or optical sensor.
The number of magnets is typically ½ the number of cylinders of the engine. The magnets are position such that the sensor outputs a positive or negative pulse earlier than the maximum advance BTDC that the engine can use. The ignition controller calculates a time delay from that pulse, based on RPM and possibly MAP to fire the ignition system at the programmed advance point. The spark is then often switched to the correct cylinder by a conventional distributor. The distributor often has it's own ignition advance, based on RPM, but in that case it does not control the actual advance, but is only there so the rotor in the distributor points to the correct cylinder terminal.

For these crank trigger setups program the number of magnets in the "Teeth in Trigger wheel" field. Set the number of extra or missing teeth to 0.

Then measure the offset by rotating the crankshaft and note down the degree number (BTDC) for each change of the sensor output. Also note wether the change is a positive edge or a negative edge. The degrees BTDC last change of output before TDC of cyl. 1, and it's pulse edge type, should be used to program the offset (and remember BTDC offsets are negative numbers).

10. Types of Speed, RPM and Frequency sensors

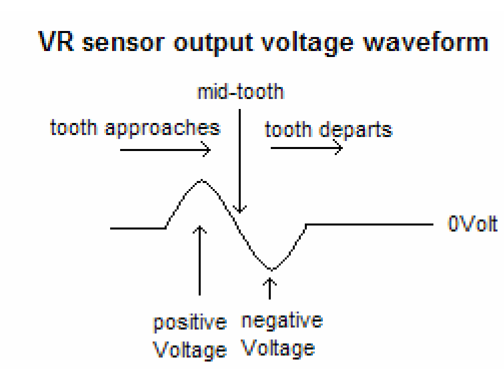
Many times in measureing a vehicle, rotational speeds need to be measured. Vehicle speed itself is also typically measured by wheel or driveshaft rotational speed. This chapter discusses the different kinds of sensors to detect rotational speed and how to connect them to an SSI-4, DL-32 or LMA-3. Some of these sensors use the magnetic properties of gear or bolt heads to detect rotational speeds. With those sensors it's important that the gear or protrusion sensed is magnetic. Some stainless steels are not. Easy test is if a magnet sticks, it's magnetic.

10.1 VR (Variable Reluctance) sensors

These are the most commonly used rotational speed sensors used in Automobiles today. Their advantage is their mechanical robustness and simple (and inexpensive) construction. Also they allow high precision in detection of rotation angles and are very impervious to tolerances or dirt in the measurement aparatus. That's why they are used as crank or cam angle reference sensors. Their disadvantages are:

a. They have a low speed limit, depending on their construction. Rotational speed MUST be above a certain minimum speed before they can sense.
b. They require special electronics (VR sensor amplifier) to condition their output signal before it can be used by more typical electronics devices.
c. Maximum gear tooth frequency is about 15 kHz.

A VR sensor is basically a cylindrical magnet with a coil of thin copper wire wound around it.
As a ferromagnetic material (steel or iron gear tooth) approaches, the magnetic field of the magnet strenghtens and when the gear tooth departs it weakens.
Any changing magnetic field crossing a conductor will induce a voltage in that inductor. The coil serves as such a conductor. The resulting voltage when a gear tooth passes under a VR sensor looks like this:



When the gear tooth approaches, the magnetic field strengthens and a positive voltage gets created. (by convention, the voltage direction is positive for an approaching tooth). The coil, by that convention, has a positive and a negative end.
In mid-tooth, the field is constant (not changing) and the induced voltage is zero (crosses the 0V line). As the tooth departs, the field weakens and a negative voltage is created. The VR sensor amplifier "arms" itself when it sees a positive voltage. When the voltage crosses 0V, it outputs a pulse to the measurement system and disarms itself again.
Therefore a VR sensor with amplifier mounted on a gear with 6 teeth would output 6 pulses per rotation. The frequency is number of teeth times the rotations per second. Or RPMs would be frequency * 60 divided by the number of teeth.

To use a VR sensor with the SSI-4, connect the +side of the VR sensor to the VR+ input of the SSI-4, the –side to the VR- input of the SSI-4. With the DL-32 or LMA-3 an external VR sensor amplifier is needed. See the DL-32 or LMA-3 manuals for details.

10.2 Optical sensors

These sensors react to the difference in reflectivity between a reflective mark on the measured shaft and the rest of the shaft. See chapter 5.2 for an example of a DIY optical sensor. The advantage of optical sensors are:

a. Simple and inexpensive
b. Light weight
c. Very high maximum frequency (up to 1 MHz).
d. No minimum frequency

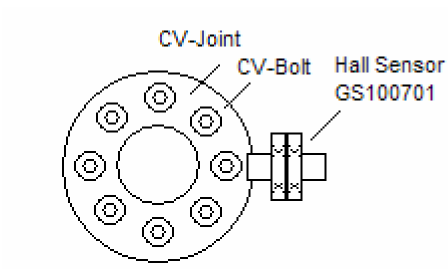
Their disadvantages are:

a. Sensitive to contamination (dirt) on the reflective surface.
b. Lower temperature range (only up to 80 degC typical) compared to VR sensors.

The description on how to connect and calibrate an optical sensor is described in chapter 5.2

10.3 Hall Effect sensors

Hall effect sensors rely on the property of some special semiconductors to output a voltage when they are in a magnetic field.
Hall sensors come in many different varieties. Some have an analog output voltage, others have trigger electronic built in that outputs the hall sensors supply voltage when the magnetic field strength is above a built-in threshhold and low when not.
Some hall sensors have built-in magnets and can detect the change in the magnetic field when brought in proximity to a ferromagnetic material (steel or iron, but not some stainless steels). These sensors are often very convenient to use. One example is to sense the bolts on a driveshaft CV joint to measure wheel speed:



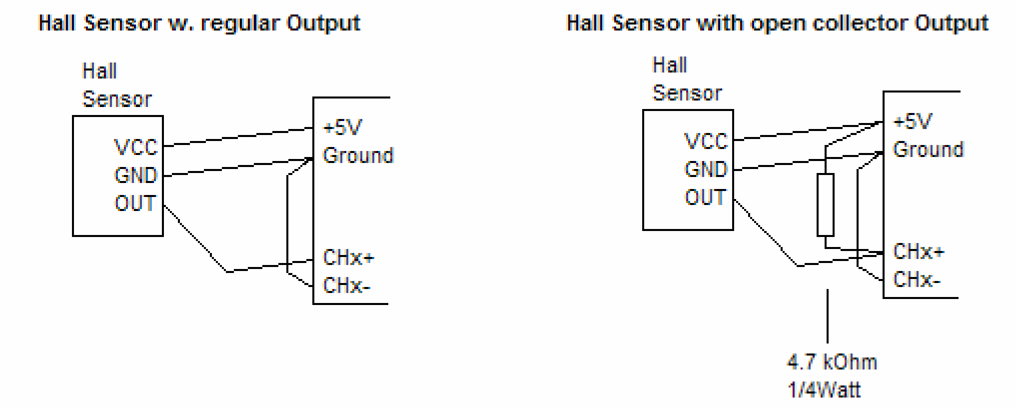
The hall sensor used in this case is a Cherry GS100701 with built-in magnet. It can be found at www.digikey.com as P/N CH398-ND.
Sometimes even the edges of a large retaining nut can be used to detect rotational speed with these kinds of sensors.

Hall sensors without built-in magnets are also often used for crank triggers. In that case the magnets are attached to the measured shaft. This is often the case in crank triggers for crank trigged ignition systems.

Hall effect sensors typically have 3 wires: Supply voltage, output and ground.

Some hall sensors, including the one indicated, have what's called a open collector output (OC output). This means, they don't output a voltage, but instead switch the output to ground when a magnetic field is detected.

Example hookups for Hall sensors to the SSI-4, LMA-3 or DL-32:



A Hall sensor with an open collector output needs a load resistor (example 4.7k Ohm between it's output and +5V.

The advantages of hall effect sensors compared to VR sensors are:

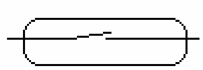
a. No special amplifier or signal conditioning required
b. Work with many irregular ferromagnetic shafts
c. No minimum speed (operate down to zero speed)

The disadvantages of Hall sensors are:

a. Cost
b. Angular precision is not high enough for trigger wheel sensing
c. High temperature sensitive
d. Maximum detection frequency is typically less than 20kHz

10.4 Reed Switches

A reed switch is just a relais contact made of thin ferromagnetic material, enclosed in a glass case. The contacts have a very small distance from each other so normally they don't make contact.



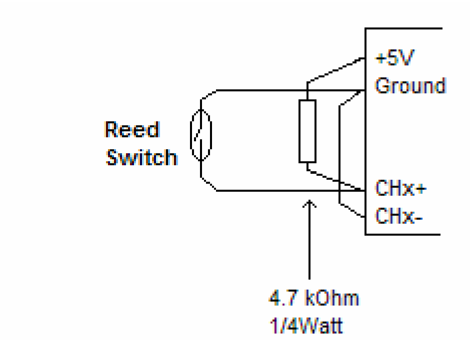
When in a magnetic field, the contacts get magnetized and attract each other. If the magnetic field is strong enough, they touch and the switch is closed. This means they can only be used when magnets are attached to the shaft to be measured.
Their advantages are:

a. No minimum rotational speed
b. Very inexpensive
c. Large temperature range

Their disadvantages are:

a. Limited lifespan of the contacts (few million on/off cycles)
b. Contact “bounce” can cause false measurements
c. Requires attached magnets on measured shaft
d. Vibration sensitive
e. Maximum detection frequency is less than 100 Hz to a few hundred Hz, depending on switch. Highr frequency capability makes switch more vibration sensitive.

Because reed switches do not output voltage pulses they require a load resistor.
An example hookup for a reed switch is shown below:



11. Revision History

6/27/06 – Initial Release